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Validation of water level predictions in Norwegian waters
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Alastair D. Jenkins, Harald Engedahl, Bruce Hackett, Bjørn Åge Hjøllo & Kristine Gjesdal

Abstract

This report presents the results of the 'Opera' project, whose objective is to evaluate the performance of a new implementation of the MI-POM hydrodynamic model in the operational forecasting of sea level in Norwegian coastal waters. The new implementation is three-dimensional, and can be run in both a vertically-homogeneous (3DH) and a baroclinic (3DB) mode. Both implementations include the astronomical tides, and for operational forecasting, these tidal constituents should be subtracted in order to predict the meteorologically-induced part of the sea-level variations. In order for the new model to be applied to operational forecasting, the mean sea level should be adjusted, and attention should be paid to the fact that the model predicts some small artificial oscillations of 0.5–1 day period in northern Norwegian coastal waters.

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RESEARCH REPORT

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Abstract

This report presents the results of the 'Opera' project, whose objective is to evaluate the performance of a new implementation of the MI-POM hydrodynamic model in the operational forecasting of sea level in Norwegian coastal waters. The new implementation is three-dimensional, and can be run in both a vertically-homogeneous (3DH) and a baroclinic (3DB) mode. Both implementations include the astronomical tides, and for operational forecasting, these tidal constituents should be subtracted in order to predict the meteorologically-induced part of the sea-level variations. In order for the new model to be applied to operational forecasting, the mean sea level should be adjusted, and attention should be paid to the fact that the model predicts some small artificial oscillations of 0.5–1 day period in northern Norwegian coastal waters.

Keywords

Water level, hydrodynamic model

Disciplinary signature ....

Responsible signature ....

Contents

1 Introduction

The current DNMI operational ocean model is run with a 20 km grid, and covers the Nordic Seas west to Iceland and also the Barents Sea. The model does not take account of tidal forcing. Storm surges (the meteorological component of the water level) are forecast using an appropriate model implementation: a vertically-homogeneous model is used in this case. Forecasts of depth-dependent current are produced using a full three-dimensional model implementation: these forecasts are used in, for example, oil drift predictions. Both model implementations are versions of the three-dimensional ocean model MI-POM (DNMI version of the Princeton Ocean Model).

A new version of MI-POM has already been developed further through external projects for oil companies, and is used today for specific forecast studies and contracts. The the model domain has been extended westwards to Greenland, and the new model also takes account of tidal forcing. A number of corrections and improvements have also been made in the program code, and a version has been developed which can be run efficiently on parallel machine architectures.

Within the project OPERA, the existing operational ocean model is to be replaced by the extended, improved and more efficient version, which also can be run on parallel computers such as the T3E. The basis of the model is to be the version which is currently used for special forecasting projects (Ormen Lange). The upgrading work will particularly emphasize the following:

1. Validation of computed tides and total water level, and necessary additional model improvements (Tasks 1 and 2);
2. Trial running of the model on parallel platforms and implementation of the new 3DB model in the operational model suite (Task 3);
3. Presentation and application of model results, particularly for use in oil drift simulations; and
4. Training and information to internal and external users (Tasks 4 and 5).

Tidal measurements and predictions for validation of the models have been obtained from outside institutions, principally Sjøkartverket (SKSK).

2 Models and data used

2.1 Models

The MI_POM operational ocean model used at DNMI is run operationally on a 20 km grid extending from the north Atlantic to the Arctic Ocean; nested domains at higher resolution are also run for special forecasts. At present, the operational predictions yield only storm surge, i.e., the changes due to atmospheric forcing. Tides are not included since the model tides have hitherto been judged to be no better than tide tables. In order to take the tides into account, tidal forcing is introduced at the open boundaries. This is done by specifying sea surface height and depth mean currents from tidal models. In addition, to enhance the representation of the tides in Norwegian waters, forcing by the astronomical tidal potential is included in the model code. Adding tides to the prediction model also benefits the assimilation procedure by removing the need for detiding the observations before assimilation. Our rationale is that it is better to produce tides in the prediction model than to remove them from observations by purely statistical manipulation (as for WLR data) or by a separate tidal model (as for altimeter data). The premise for this approach is that the errors introduced by manipulation of the data are at least as large as the errors in the tidal representation in the model; in other words, that the model validates well for tides.

To verify the coding and to assess the benefit of adding the tidal potential, a number comparative model runs were performed.

MI_POM may be run in three different modes:

- 2D: purely two-dimensional, where only the barotropic equations are solved.
- 3DB: fully three-dimensional, baroclinic, i.e., with varying temperature and salinity.
- 3DH: three-dimensional with homogeneous temperature and salinity.

For storm surge forecasting at DNMI, MI_POM is currently run in 3DH mode using twelve sigma-levels. Operationally, a dedicated model run is performed twice daily in this mode on a 20 km Norwegian waters grid (Fig. 1). The rationale for running in this mode instead of the more common 2D mode is better definition of the surface and bottom stresses. Past experience with storm surge simulation has shown only small differences between 2D and 3DH mode; differences are mainly in shallow waters. In addition, in the operational suite a 3DB model without tides and with 17 sigma-levels is run for the same area in order to compute currents for use in e.g. oil drift simulations.

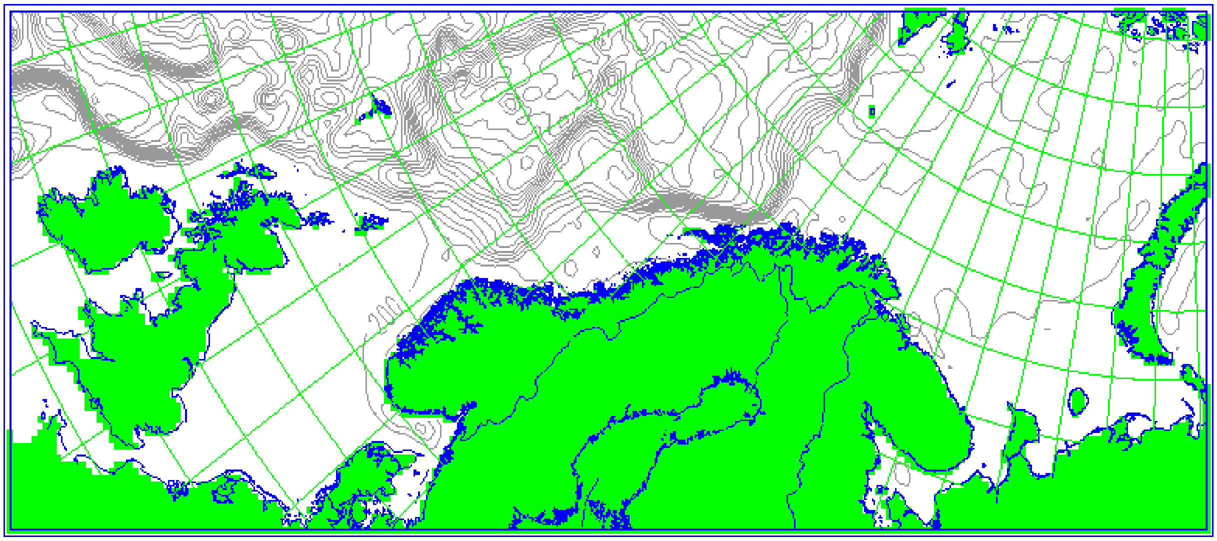

Fig. 1. The 20 km Norwegian waters grid.

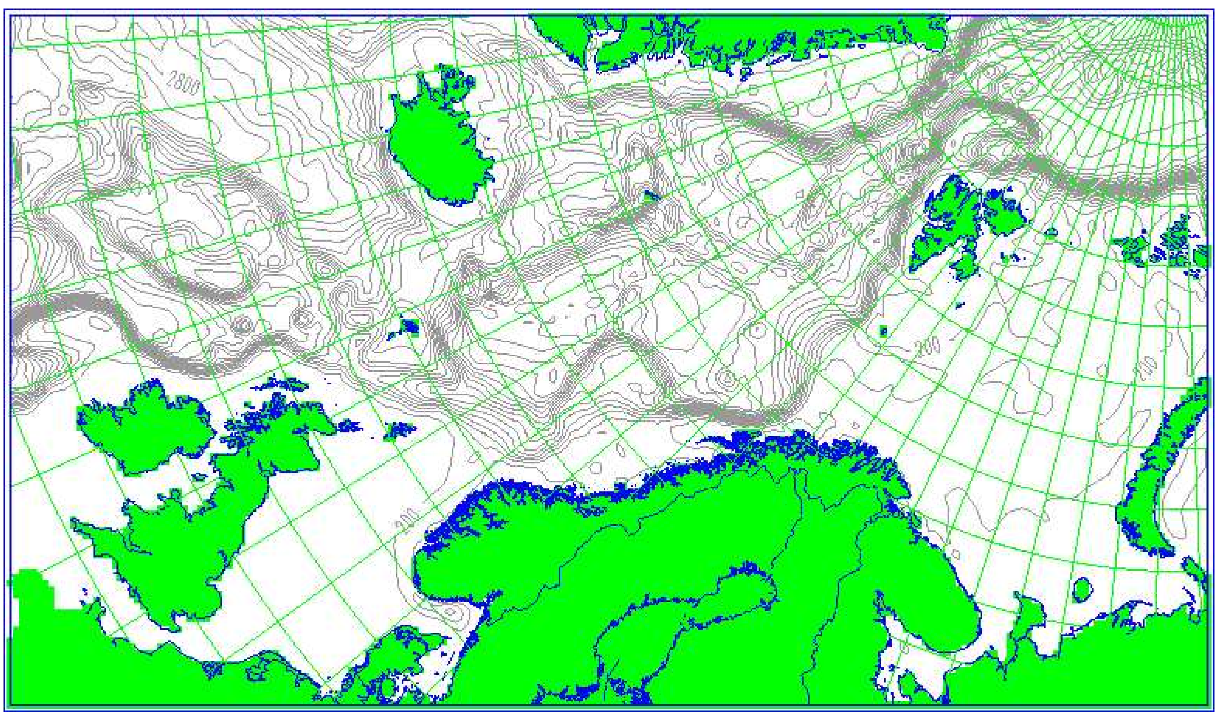

Fig. 2. The extended 20 km Norwegian waters grid.

At the same time, additional operational runs in 3DB mode have been performed for some time at DNMI to meet the increasing interest for forecast products requiring a 3D baroclinic model.

These products include profiles of temperature, salinity and current, and the effects of mesoscale eddies and tides are important. Operational forecasts are currently generated once daily, both at large scale (extended Norwegian waters 20 km grid—Fig. 2) and on eddy-resolving grids (Skagerrak 4 km, Norwegian shelf 4 km and Oslofjord 800 m). These runs include tidal forcing and are in addition to the 3DH storm surge run and the 3DB run (neither of which include tides). The predictive skill for storm surge of MI_POM in 3DB mode has hitherto not been assessed.

2.2 Validation data

2.2.1 Water level measurements

Hourly measurements of water level from Norwegian standard ports were provided by SKSK, for the following two-month periods: 1998 September–October, and 1999 March–April. For comparison with the model results, the measurements were referred to mean sea level ('Middelvann') according to the datum information provided by SKSK.

2.2.2 Tidal predictions

Hourly tidal predictions of water level from Norwegian standard ports were provided by SKSK, for the same two two-month periods (1998 September–October, and 1999 March–April), and referred to the same datum as the measurements.

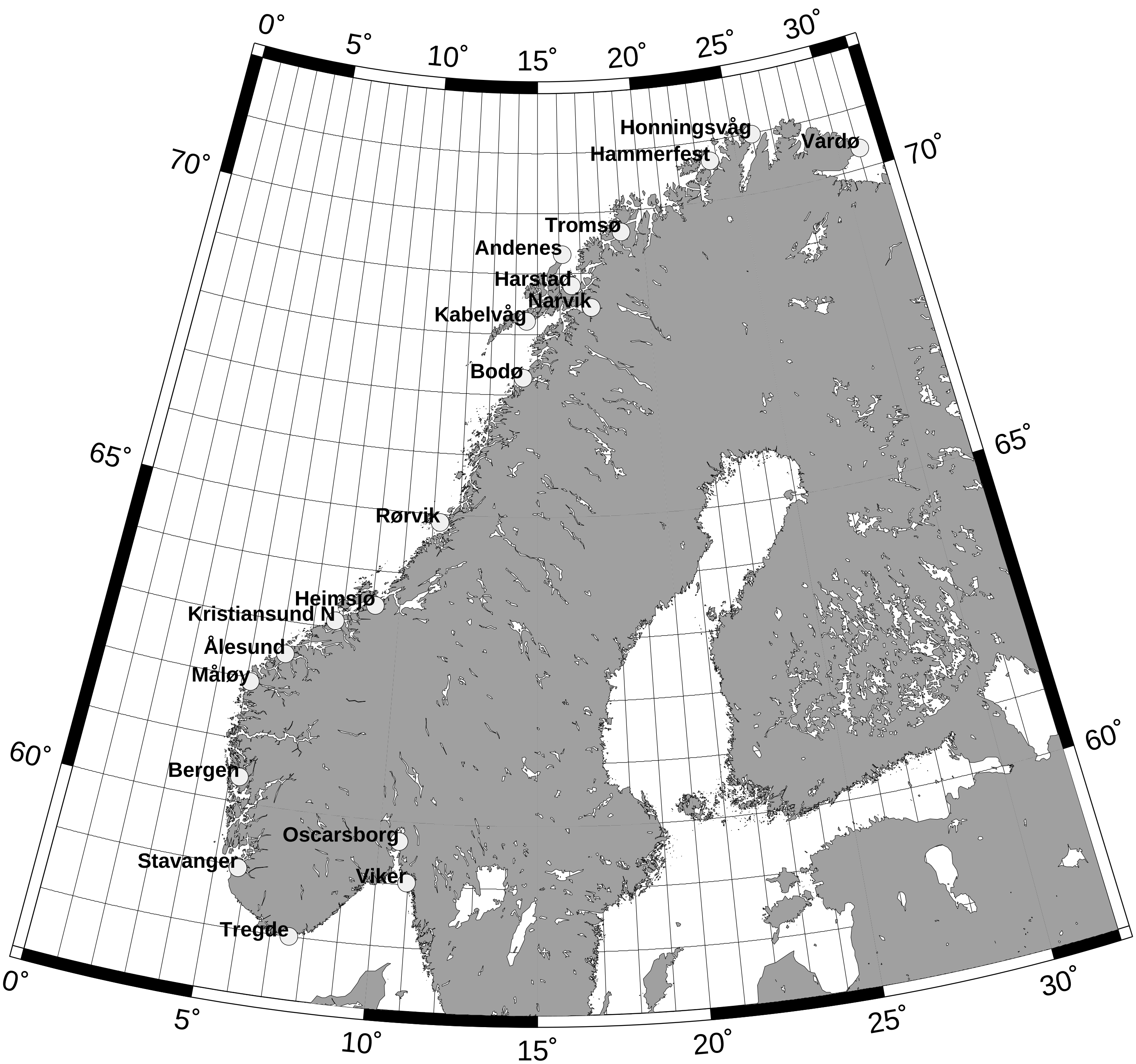

Fig. 3. Map showing the standard ports for which measurements and tidal predictions were obtained.

3 Results

3.1 Tides

Parallel runs of MI_POM in each of the three modes were performed for the same model grid and period, forced only by tides.

- Model domain: extended Norwegian waters (20 km)
- Period: March-April 1999
- Forcing: tidal harmonics (8) as lateral boundary conditions
- Output: hourly SSH fields and time series at selected grid points

Cotidal charts for M_2 and K_1 have been drawn for each of the three runs, and are presented in the project report for HAVASS2 (http://fou.dnmi.no:8001/seksjoner/hav/prosjekter/havass2/):

For M_2, the cotidal charts are essentially identical.

For K_1, there are minor differences:

- slightly lower amplitudes in North Sea and White Sea in 3DH run
- the odd amplitude maximum on Tromsøflaket in the 2D and 3DH runs

It is concluded that there are insignificant differences in the tidal response between the three model modes, at least for the 20 km resolution grid used here.

Comparison with other tide models

The cotidal charts from the MI_POM runs may also be compared with the models of Flather [1] and Gjevik [2]. These models are considered well validated tidal models of the North Atlantic—Nordic Seas—Arctic Ocean. Tidal harmonic constants from these two models have been obtained and merged into a tidal data base at DNMI. For the MI_POM runs performed here, the harmonic constants are interpolated to the model grid and then the values along the open boundaries are used to calculate the tidal forcing. The interpolated fields of harmonic constants constitute cotidal charts of the Flather/Gjevik data on the model grid.

The MI_POM cotidal charts shown in the HAVASS2 report are very similar to the Flather/Gjevik results. (In fact, they should be identical at the open boundaries.) Considering the M_2 and K_1 constituents in turn:

M_2:

The cotidal charts from the MI_POM runs exhibit only minor discrepancies from the Flather/Gjevik results, namely,

- The amphidrome near Novaya Zemlja is further offshore.
- In the German Bight, the amplitude is about 20 cm lower and there is a phase difference of about 40°.
- On the east coast of the UK, the amplitude is about 20 cm lower, but the phase is the same.
- The amphidrome off southern Norway is located somewhat farther to the north
- The amplitude in the Skagerrak is somewhat higher, while the phases differ by up to 60°.
- In the Kattegat, there are considerable differences. While the Flather model shows a degenerate amphidrome at the northern end of Zeeland, the MI_POM runs produce a plane wave progressing into the Kattegat. Amplitudes in all model runs are small—0.2 m or less.

K_1:

For K_1, there are greater discrepancies between the MI_POM and Flather/Gjevik cotidal charts. However, the amplitudes in much of the region are small (note that the contour intervals are an order of magnitude smaller than in the M_2 figures), so that the cotidal structure is very sensitive to small model differences. The primary discrepancies from Flather/Gjevik are:

- Overall, the amplitudes are smaller by 1-2 cm.
- In the eastern Barents Sea, the amplitudes are considerably smaller—about half as big.
- The North Sea amphidrome is nearer the Norwegian coast, giving smaller amplitudes along the southern coast.
- The Barents Sea amphidrome is located farther east.
- The local amplitude maximum over Tromsøflaket is considerably larger—by about 6 cm.

Comparison of time series at coastal observing locations

Time series corresponding to seven harbour locations (Helgeroa, Tregde, Måløy, Kristiansund, Rørvik, Bodø and Narvik) have been extracted from each of the three runs and analyzed using a Matlab implementation of the tidal heights analysis subroutine.

Sample numerical values are presented for Rørvik in the following tables.Comparing the model runs, differences between 2D, 3DH and 3DB are minimal for the largest constituents (M_2, S_2, N_2, K_1).

Generally, the differences between model runs are smaller than between model and observation. Considering the dominant M_2 constituent, there is a marked difference between the models' poor performance in the Skagerrak (Helgeroa and Tregde) and good performance on western and northern coast (Måløy, Kristiansund, Rørvik, Bodø). [Narvik is difficult to simulate with a coarse grid model, since the observation point is quite far from the nearest model grid point.] In the Skagerrak, the models overestimate the M_2 amplitude by about 50%. Phase errors are small at all stations, with the 2D run showing slightly larger errors in the Skagerrak. The other semi-diurnal constituents (S_2 and N_2) show similar behavior, with the exception of the large S_2 phase errors in the Skagerrak.

The main diurnal constituents K_1 and O_1 are overestimated in amplitude, with 3DB being generally closest; diurnal phases agree more poorly with observations, with differences of 5–50°.

Conclusion: Overall, the 3DB run shows marginally the best performance of the three model runs, in terms of the rms errors.

Table 1. Tidal constituent amplitudes at Rørvik, March–April 1999, for 3 runs of MI-POM. Observed estimates are from analysis of the same period and from 1 years' (1997) data.

Constit.	**2D**	**3DH**	**3DB**	**Obs**	**Obs(97)**
Z_0	0.004	0.004	0.026	1.147	0.024
Q_1	0.013	0.014	0.015	0.020	0.024
O_1	0.065	0.053	0.029	0.048	0.047
K_1	0.098	0.096	0.089	0.054	0.077
N_2	0.165	0.162	0.162	0.162	0.164
M_2	0.767	0.758	0.755	0.793	0.788
S_2	0.279	0.277	0.276	0.322	0.272

Table 2. Tidal constituent phases at Rørvik, March–April 1999, for 3 runs of MI-POM. Observed estimates are from analysis of the same period and from 1 years' (1997) data.

Constit.	**2D**	**3DH**	**3DB**	**Obs**	**Obs(97)**
Q_1	13	3	0	358	355
O_1	353	350	18	31	40
K_1	152	152	145	166	169
N_2	294	294	294	295	285
M_2	306	306	306	309	309
S_2	347	347	346	348	347

3.2 Surge component

The measured and modelled water levels from the standard ports, after deduction of the tidal component, are plotted against each other, as scatter plots in Appendix A, and as time series in Appendix B. The following table summarizes the differences between the mean sea level predicted by the old and new models and the measurements, the tidal components having been subtracted in both cases. These differences are identical to the vertical offsets of the regression lines of slope 1.0 which are plotted in the Appendix A figures. Where available, corresponding mean sea levels computed for a run of the new model are also shown. There are differences of the order of between 0.1 and 0.2 m, the causes of which require further investigation.

Table 3. Table showing the mean sea level predicted by the old 3DH and new 3DB models minus the mean sea level shown by the SKSK measurements. The tidal components have been subtracted in both cases. The comparison with measurements is for the periods September–October 1998 and March–April 1999.

Location	**Old 3DH model minus measurements** / m	**New 3DB model minus measurements** / m	**Mean sea level from 2-year run with the new 3DB model, 1998–1999** / m
Viker	+0.14	+0.39	+0.182
Oscarsborg	+0.09	+0.35	+0.196
Tregde	+0.04	+0.27	+0.148
Stavanger	+0.02	+0.23	+0.120
Bergen	+0.06	+0.22	+0.084
Måløy	+0.03	+0.21	+0.106
Ålesund	+0.03	+0.21	+0.110
Kristiansund N	+0.04	+0.24	+0.132
Heimsjø	+0.09	+0.27	+0.109
Rørvik	+0.12	+0.28	+0.084
Bodø	+0.10	+0.28	+0.125
Kabelvåg	+0.16	+0.33	+0.118
Narvik	+0.17	+0.34	+0.129
Harstad	+0.14	+0.21	+0.036
Andenes	+0.10	+0.17	+0.032
Tromsø	+0.13	+0.19	+0.028
Hammerfest	+0.14	+0.15	−0.018
Honningsvåg	+0.10	+0.10	−0.026

In order to present the time series plots in Appendix B, it was necessary to subtract the tidal constituents computed from model results from the old 3DH and new 3DB model time series of water level, and compare them with the measured water levels with the SKSK computed tidal constituents removed. This is because the model was not able to reproduce the tidal constituents at the standard ports sufficiently accurately. In addition to differences in the mean water level, it is also noteworthy that for the standard ports in northern Norway (from Bodø to Honningsvåg), the new 3DB model also has present some extra oscillations of around 10 cm amplitude and period of 0.5–1 day. In order to make reliable operational forecasts of the meteorologically-induced sea level variations, it will be necessary to discount such artificially-generated oscillations, which are fortunately rather small compared with the tidal constituents which have amplitudes of around 1 metre in this area.

Serial and parallel model versions. The time series plots also show results for serial and multiprocessor parallel versions of the models. It can be seen that the differences between the serial and parallel model results, caused by differences in numerical rounding, are in effect negligible, hardly ever exceeding 1–2 cm.

4 Conclusion

For the purposes of operational forecasting, it is generally only necessary to predict the meteorologically-induced part of the sea level variations in areas near the coast where reliable tidal predictions may be obtained from other sources such as SKSK. Thus there would be no requirement to run a hydrodynamic forecasting model which includes the astronomical tides, in areas such as in Norwegian coastal waters where tide–surge interaction is small. For offshore locations, where tidal predictions are not so readily accessible, it is more advantageous to be able to predict the total sea level including tides.

From the analysis of the time series of model results and measurements for the Norwegian standard ports, it can be seen that in general both the old and new models give fairly reliable predictions of water level. The predicted mean water level is more accurate for the old model, which means that it will be necessary to make some further adjustments of the mean level in the new model. The new model also appears to have some spurious oscillations of 0.5–1 day period in northern Norwegian waters, but these oscillations are considerably smaller than the astronomical tidal component, and so are of rather minor practical importance for operational forecasting.

References

[1] R. A. Flather. Results from the model of the north east Atlantic relating to the Norwegian coastal current. In *Norwegian Coastal Current Symposium, Geilo*, volume II, page 31. University of Bergen, 1981.

[2] B. Gjevik and T. Straume. Model simulation of the M_2 and K_1 tide in the Nordic seas and the Arctic Ocean. *Tellus*, 41:73–96, 1989.

A Validation scatter plots

The plots shown are of modelled water level against the measured water level, in both cases with the tidal predictions subtracted. In the case of the measured water level, with data provided by Sjøkartverket (Norwegian Hydrographic Service), the Sjøkartverket tidal predictions are used. In the case of the old model, the modelled water level has no tidal component. In the case of the new model, tidal predictions obtained from a 3-dimensional homogeneous model run are subtracted. The straight lines plotted have a unit slope, and their intercept on the vertical axis is equal to the mean difference between the modelled and measured water levels.

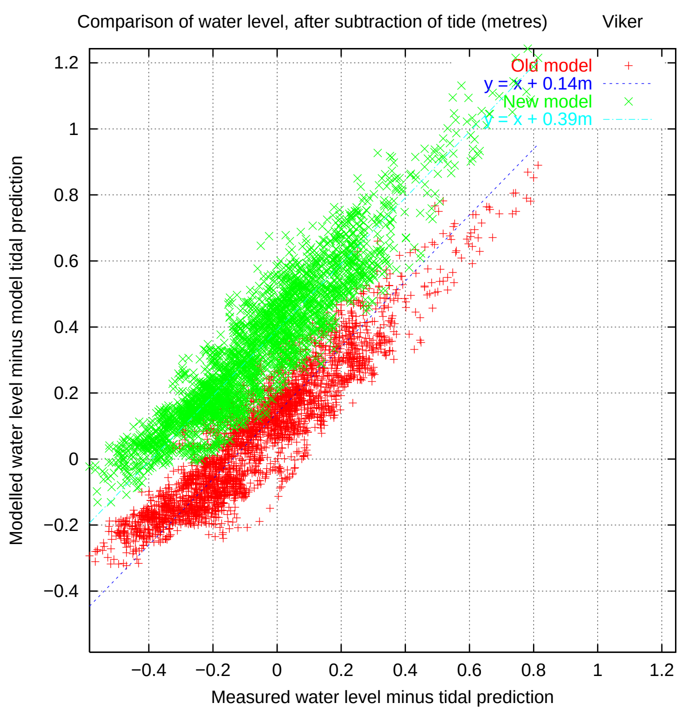

Fig. 4. Modelled *v.* measured water level for Viker

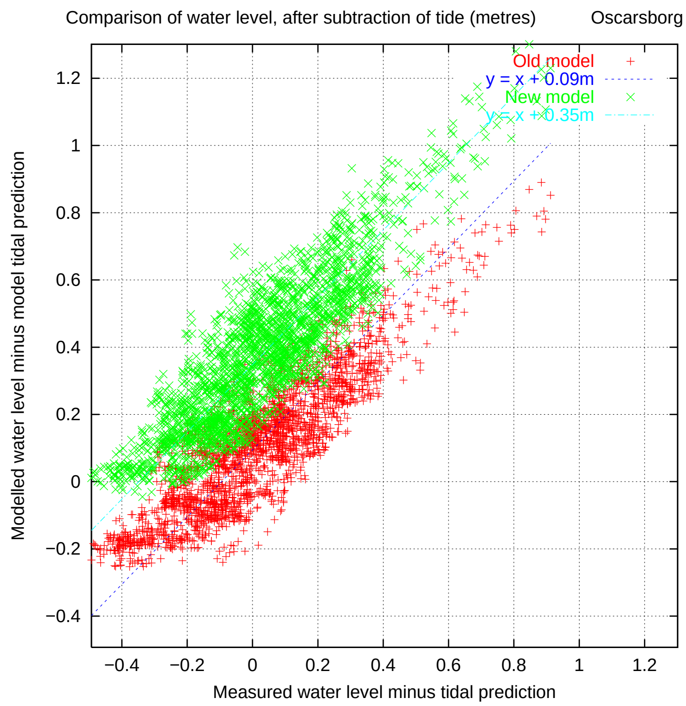

Fig. 5. Modelled *v.* measured water level for Oscarsborg

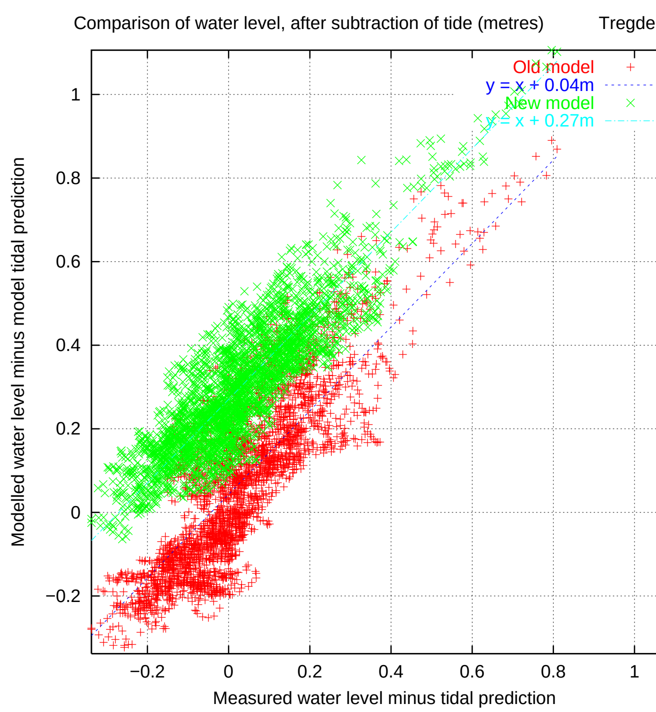

Fig. 6. Modelled *v.* measured water level for Tregde

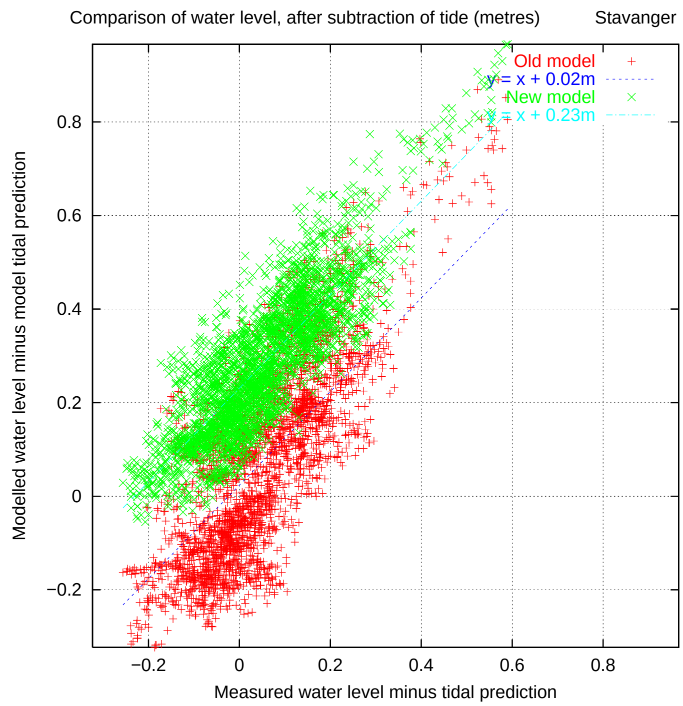

Fig. 7. Modelled *v.* measured water level for Stavanger

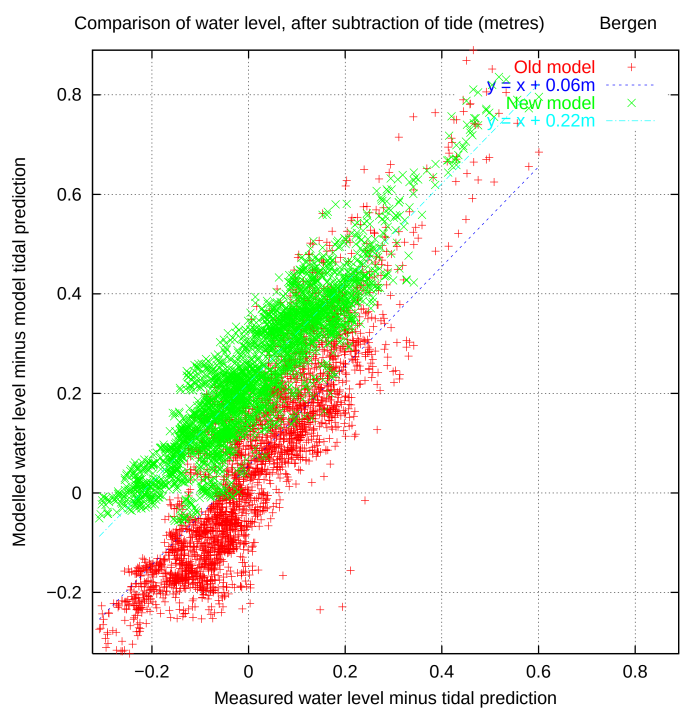

Fig. 8. Modelled *v.* measured water level for Bergen

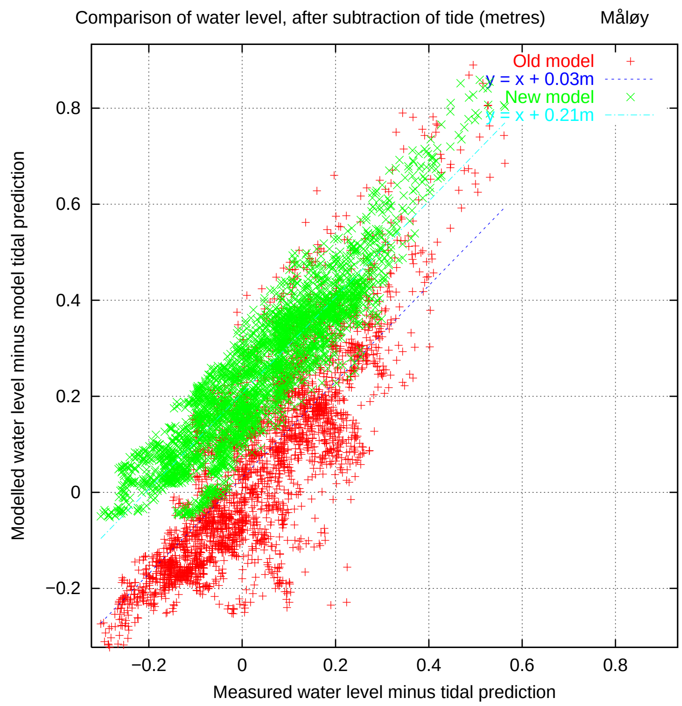

Fig. 9. Modelled *v.* measured water level for Måløy

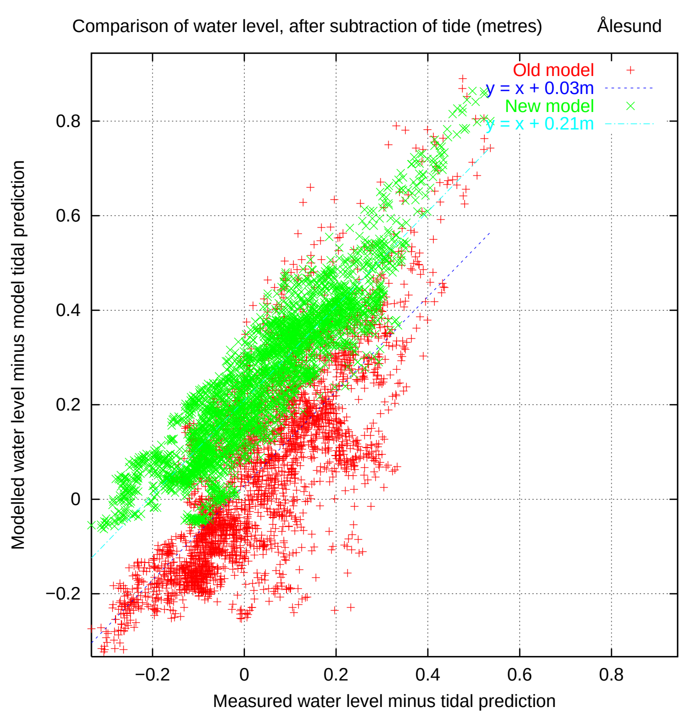

Fig. 10. Modelled *v.* measured water level for Ålesund

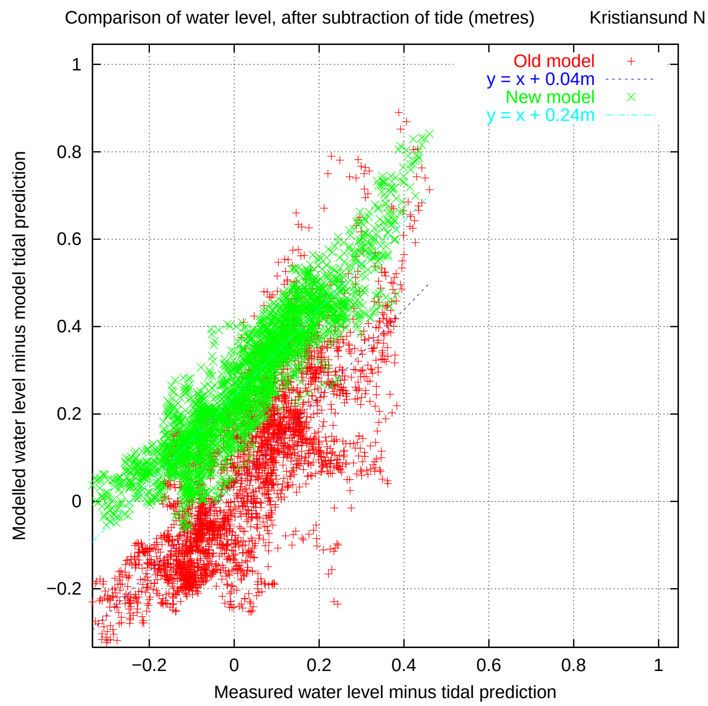

Fig. 11. Modelled *v.* measured water level for Kristiansund N

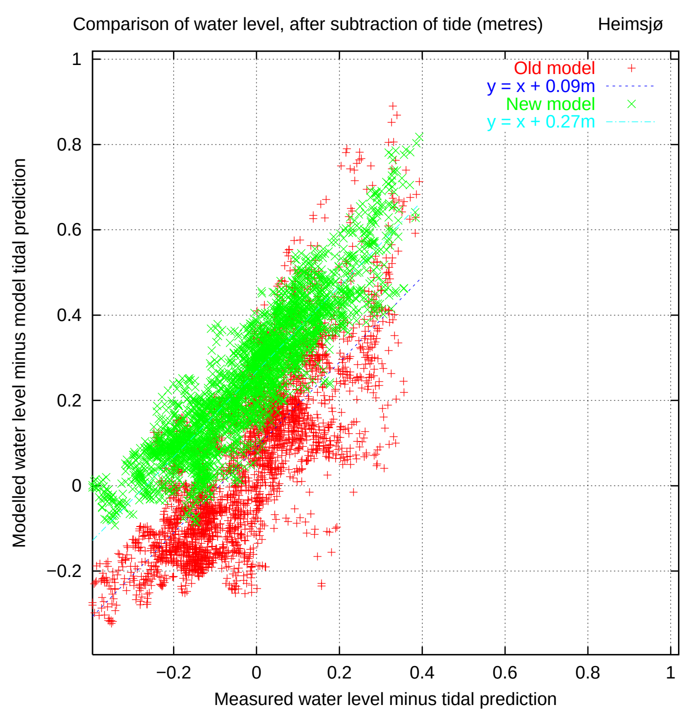

Fig. 12. Modelled *v.* measured water level for Heimsjø

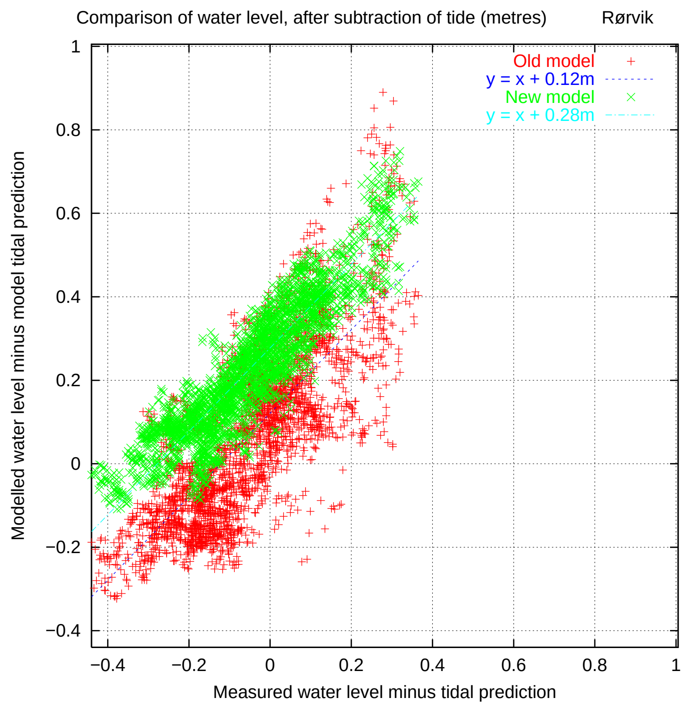

Fig. 13. Modelled *v.* measured water level for Rørvik

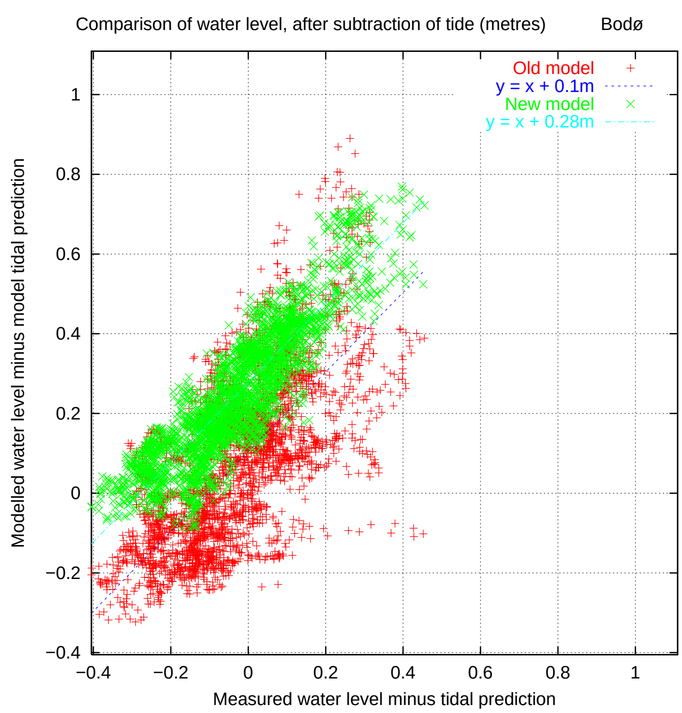

Fig. 14. Modelled *v.* measured water level for Bodø

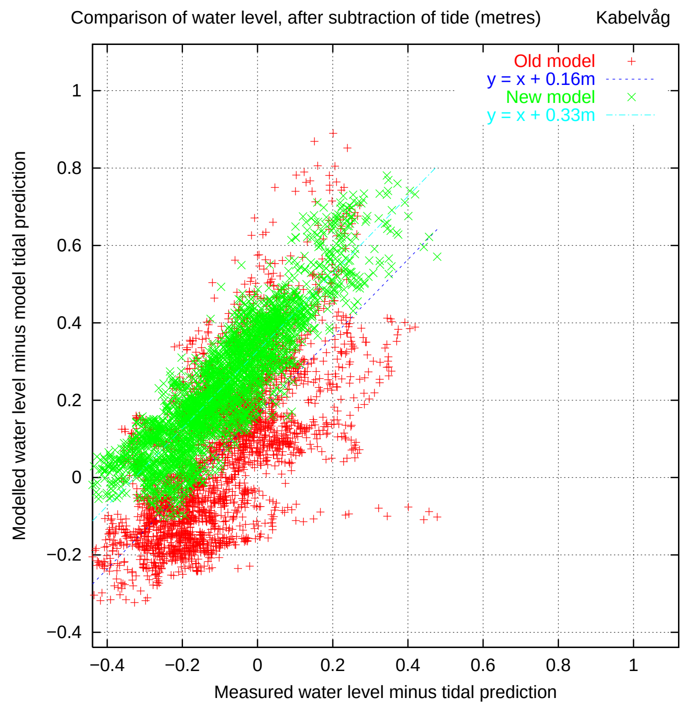

Fig. 15. Modelled *v.* measured water level for Kabelvåg

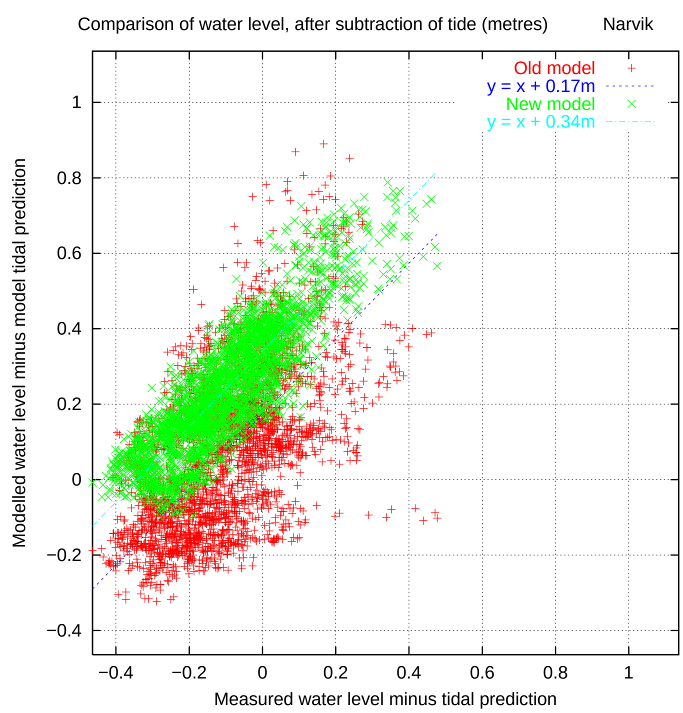

Fig. 16. Modelled *v.* measured water level for Narvik

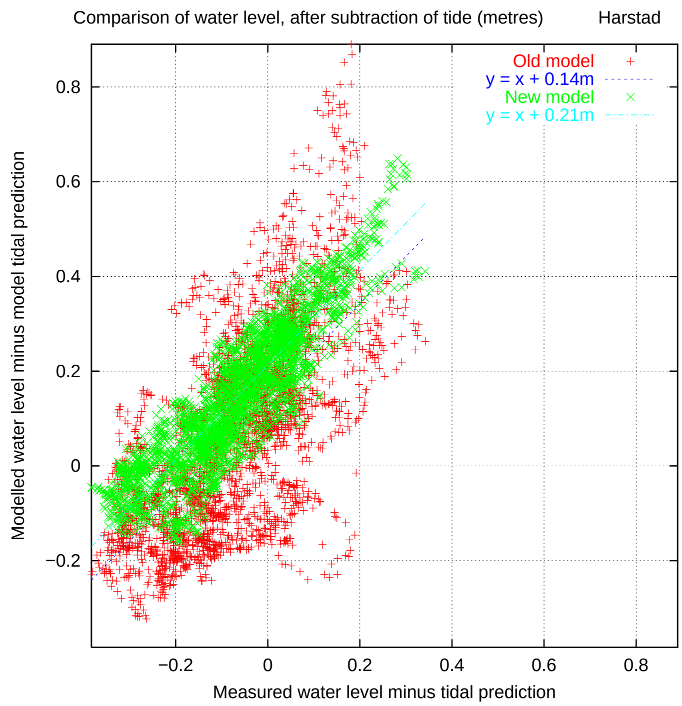

Fig. 17. Modelled *v.* measured water level for Harstad

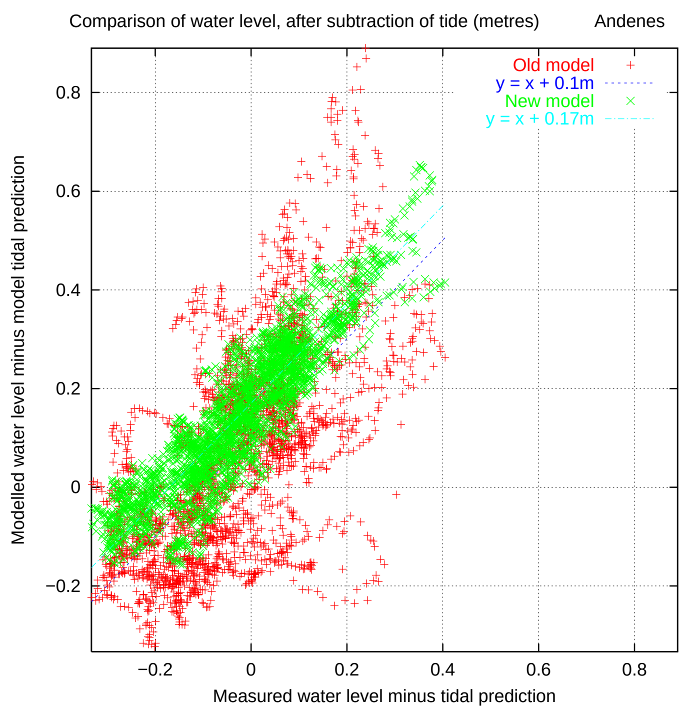

Fig. 18. Modelled *v.* measured water level for Andenes

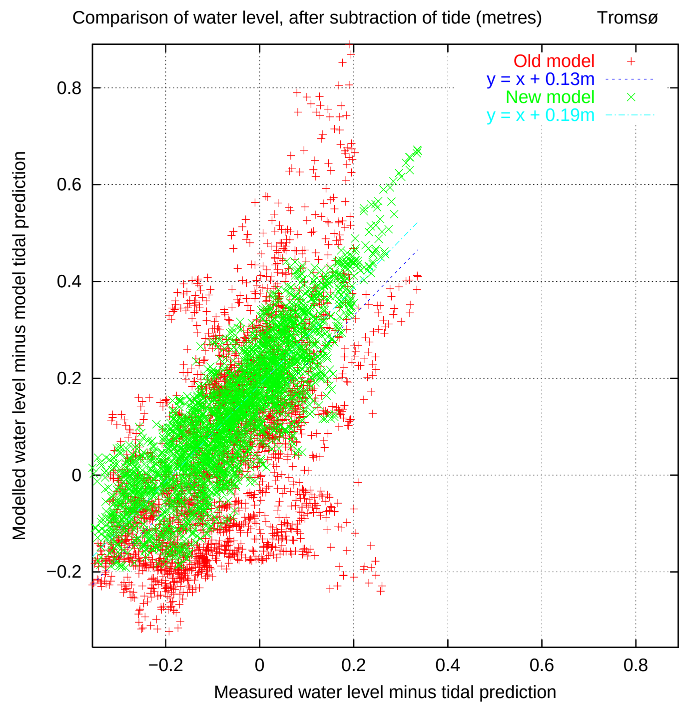

Fig. 19. Modelled *v.* measured water level for Tromsø

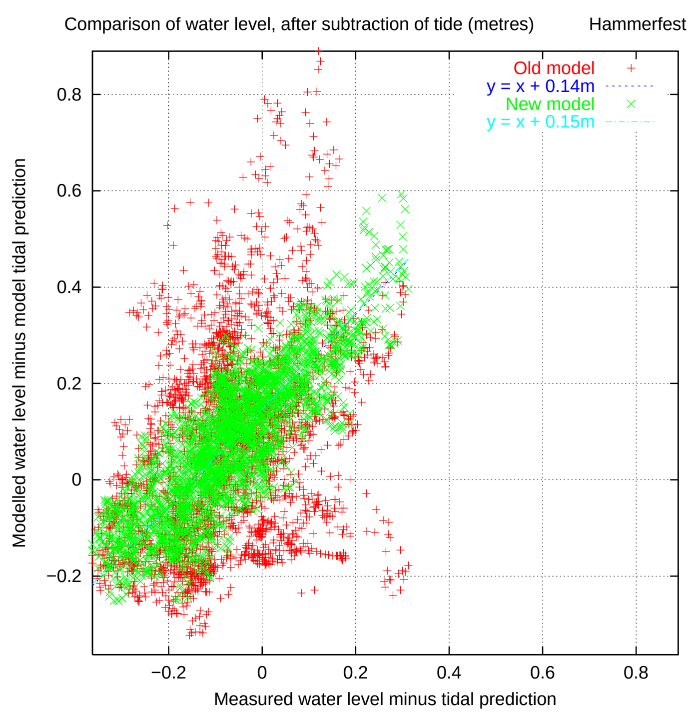

Fig. 20. Modelled *v.* measured water level for Hammerfest

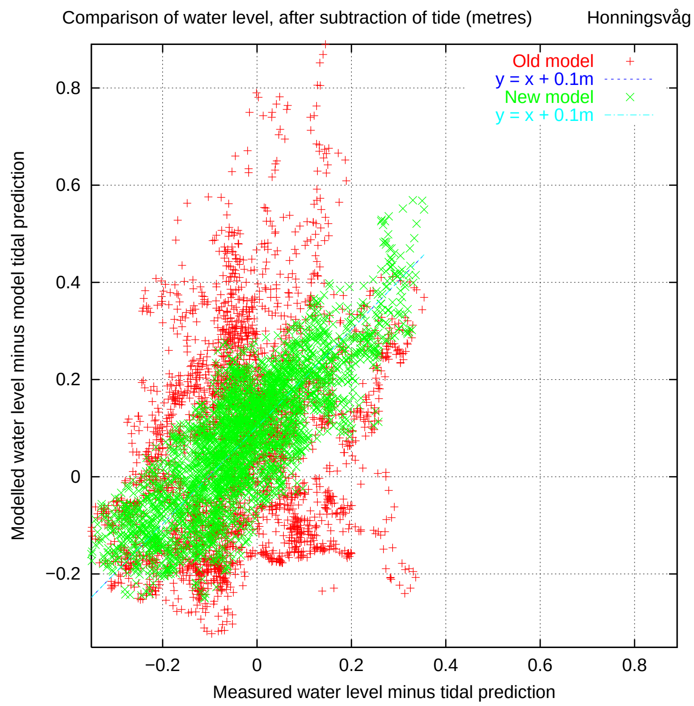

Fig. 21. Modelled *v.* measured water level for Honningsvåg

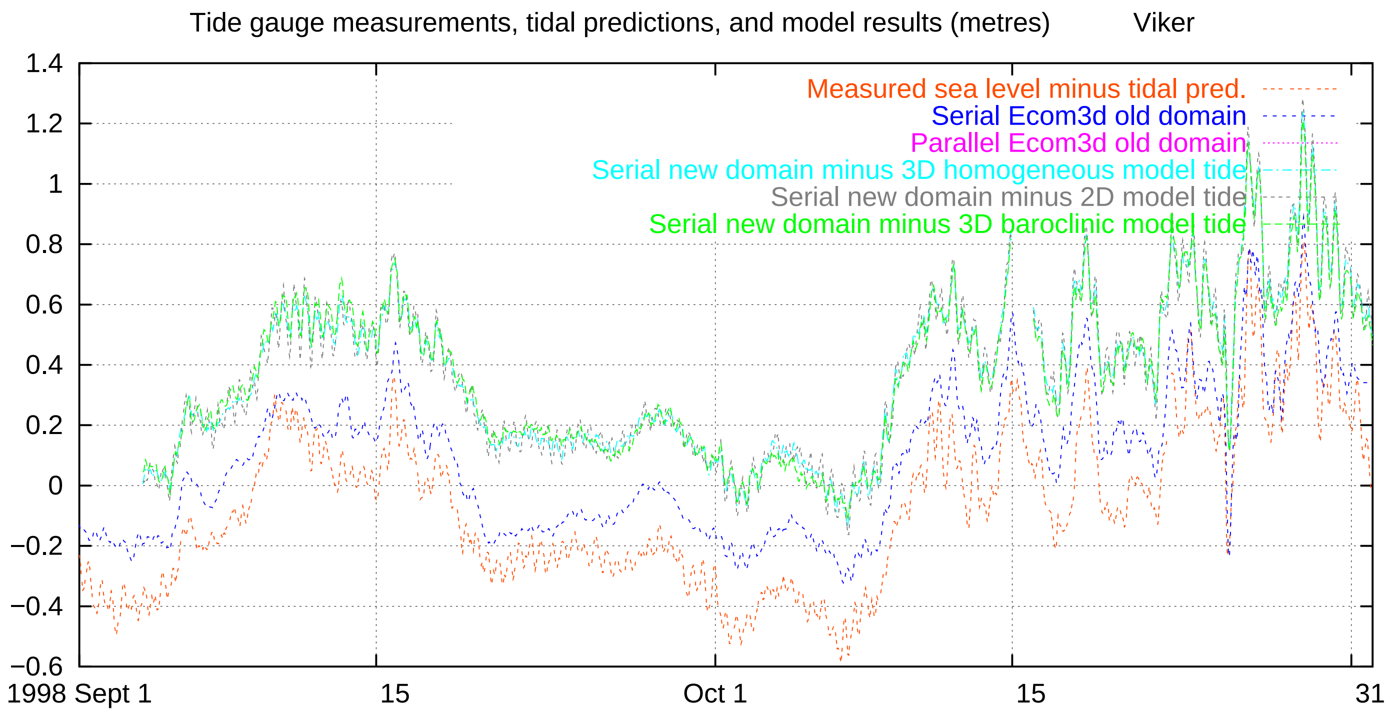

Fig. 22. Measured and modelled water level, excluding tides, Viker, 1998 September–October

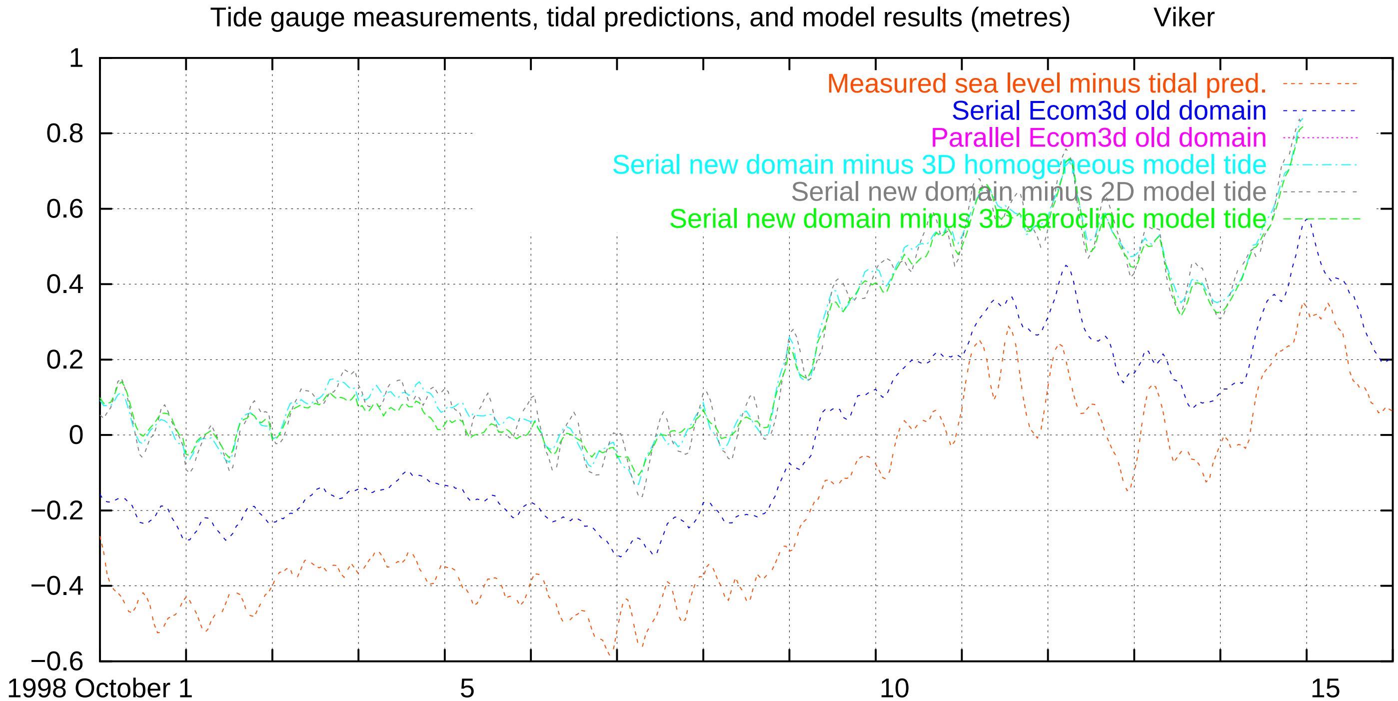

Fig. 23. Measured and modelled water level, excluding tides, Viker, 1998 October 1–15

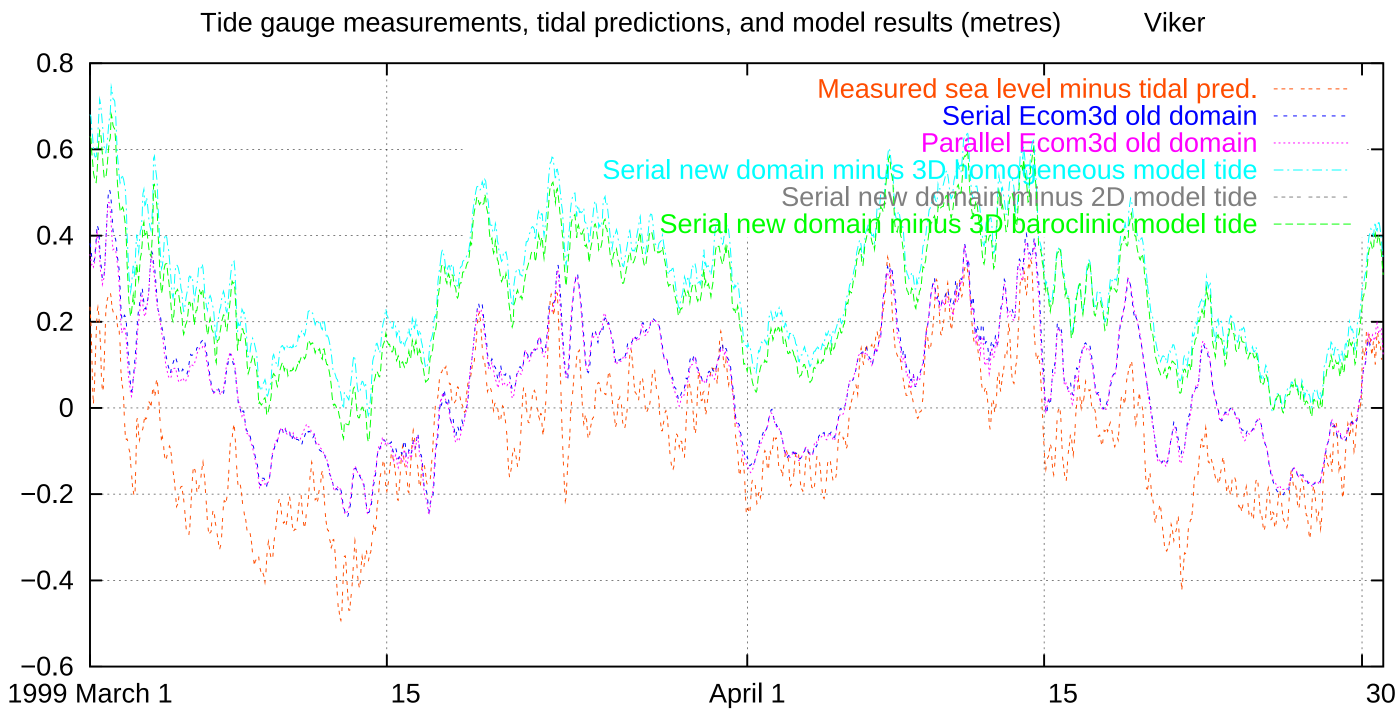

Fig. 24. Measured and modelled water level, excluding tides, Viker, 1999 March–April

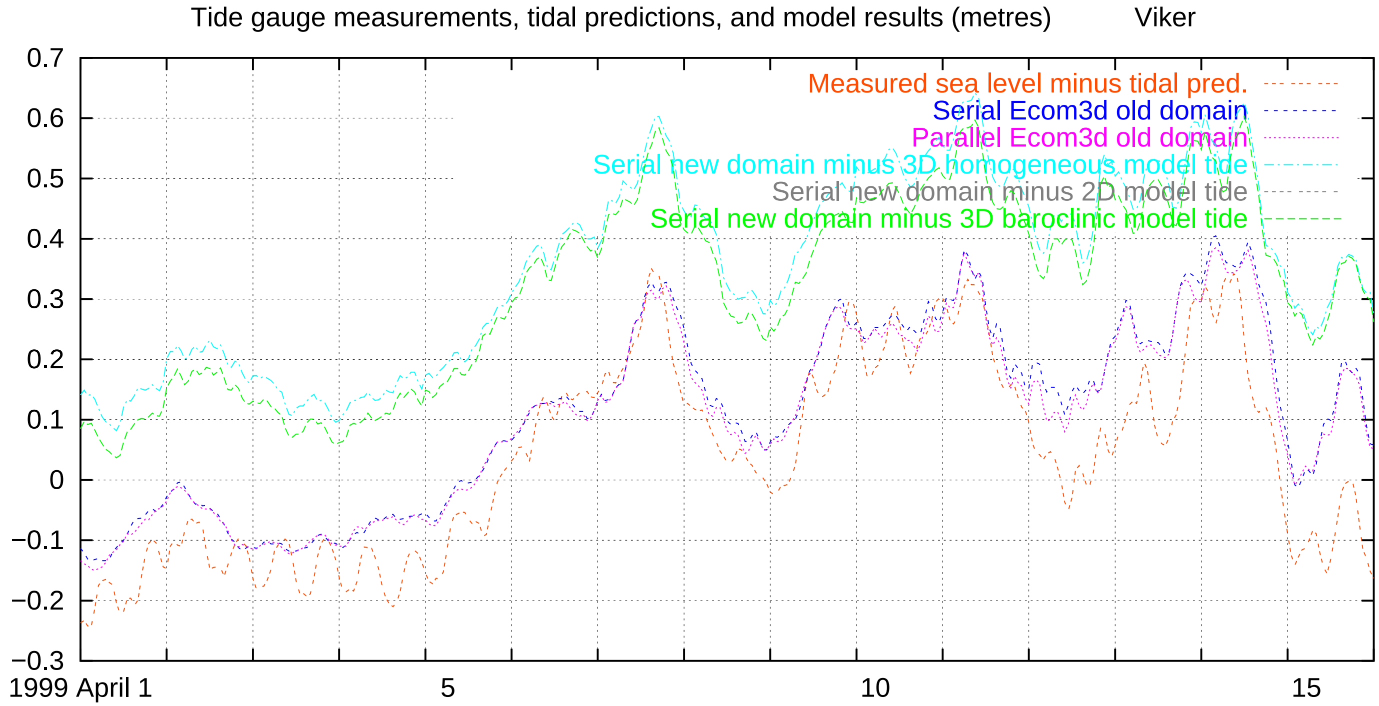

Fig. 25. Measured and modelled water level, excluding tides, Viker, 1999 April 1–15

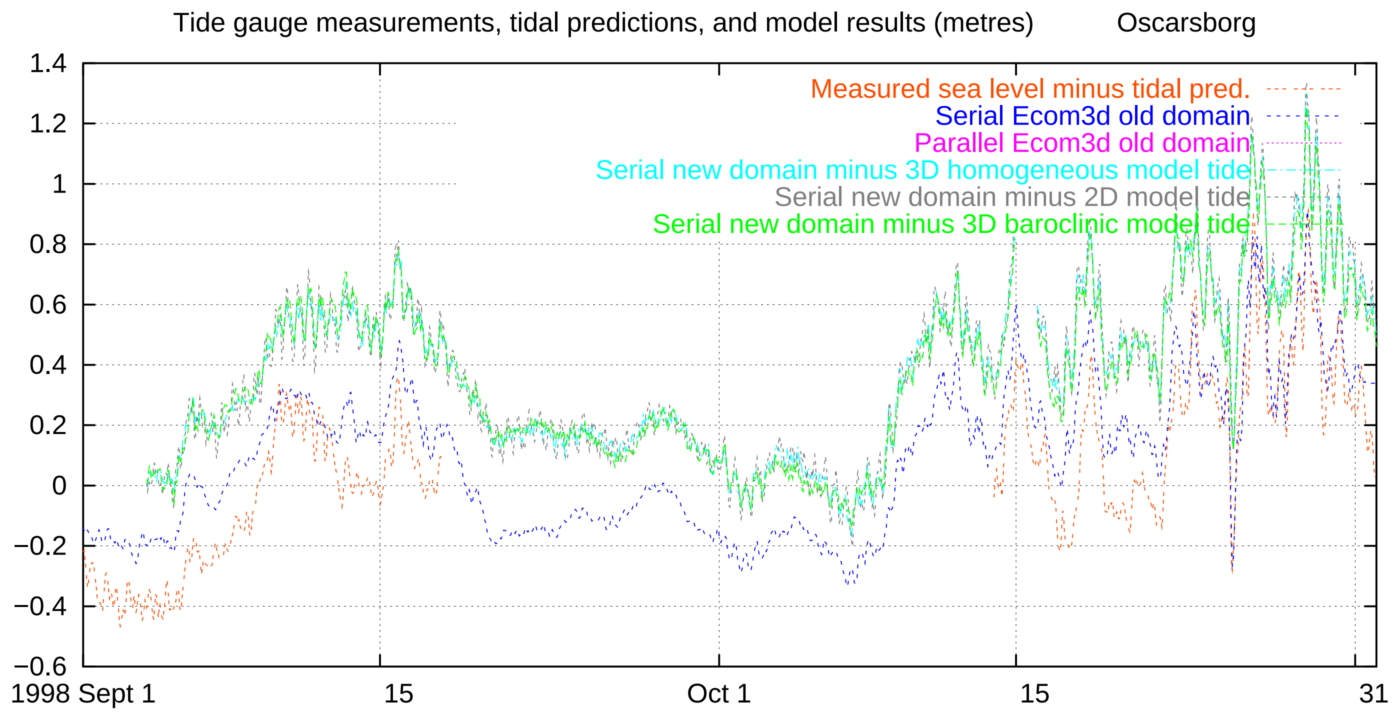

Fig. 26. Measured and modelled water level, excluding tides, Oscarsborg, 1998 September–October

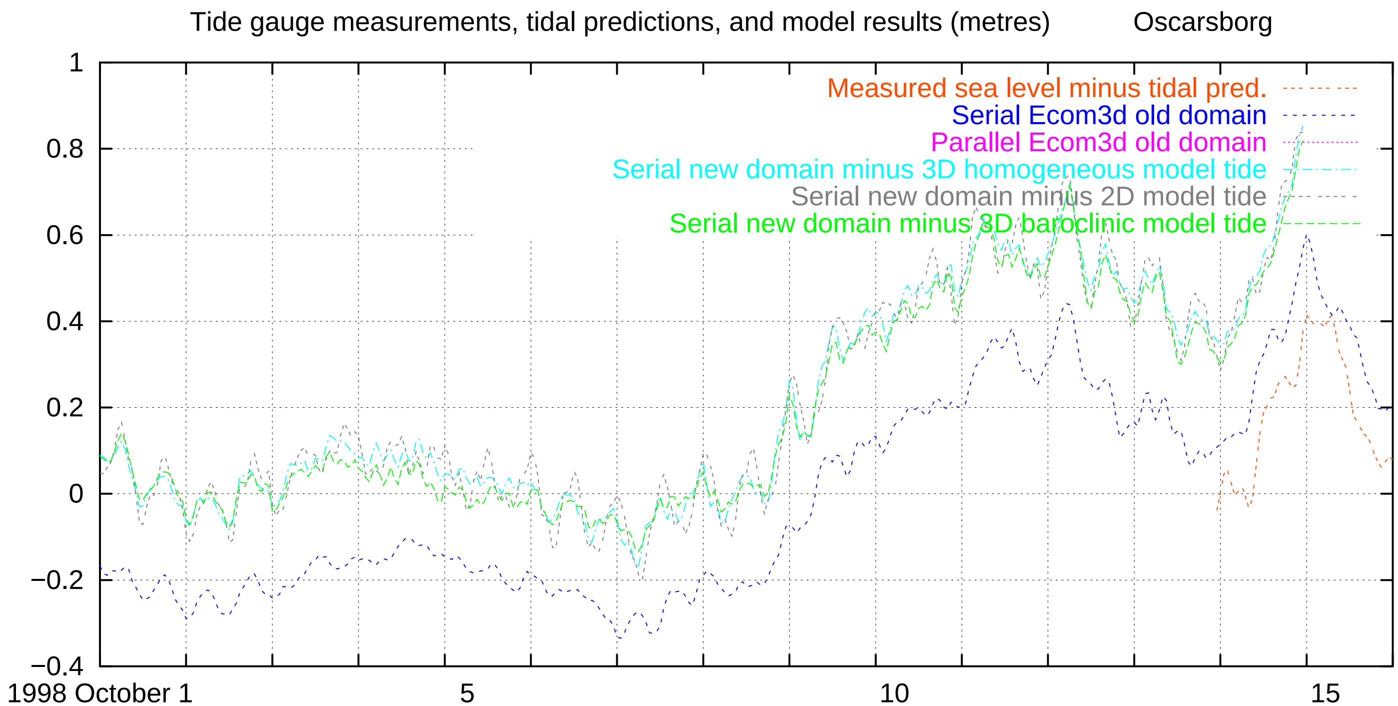

Fig. 27. Measured and modelled water level, excluding tides, Oscarsborg, 1998 October 1–15

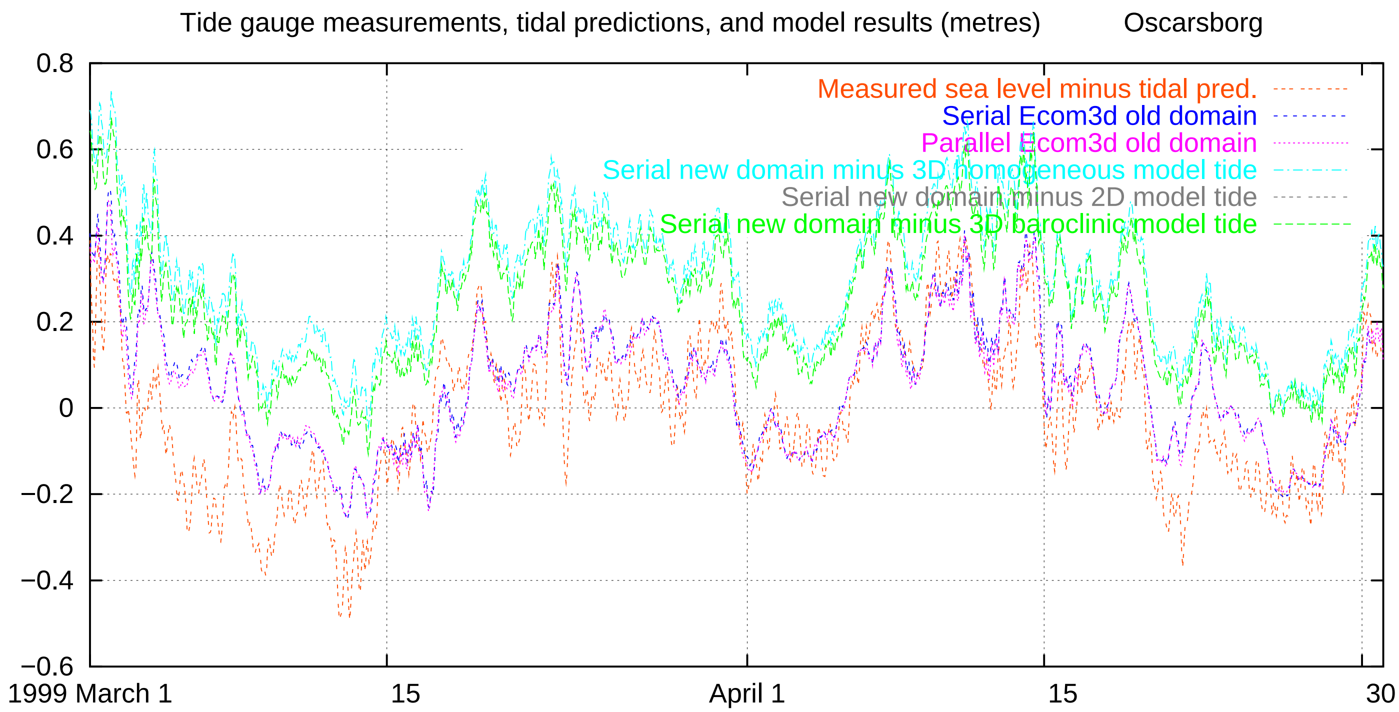

Fig. 28. Measured and modelled water level, excluding tides, Oscarsborg, 1999 March–April

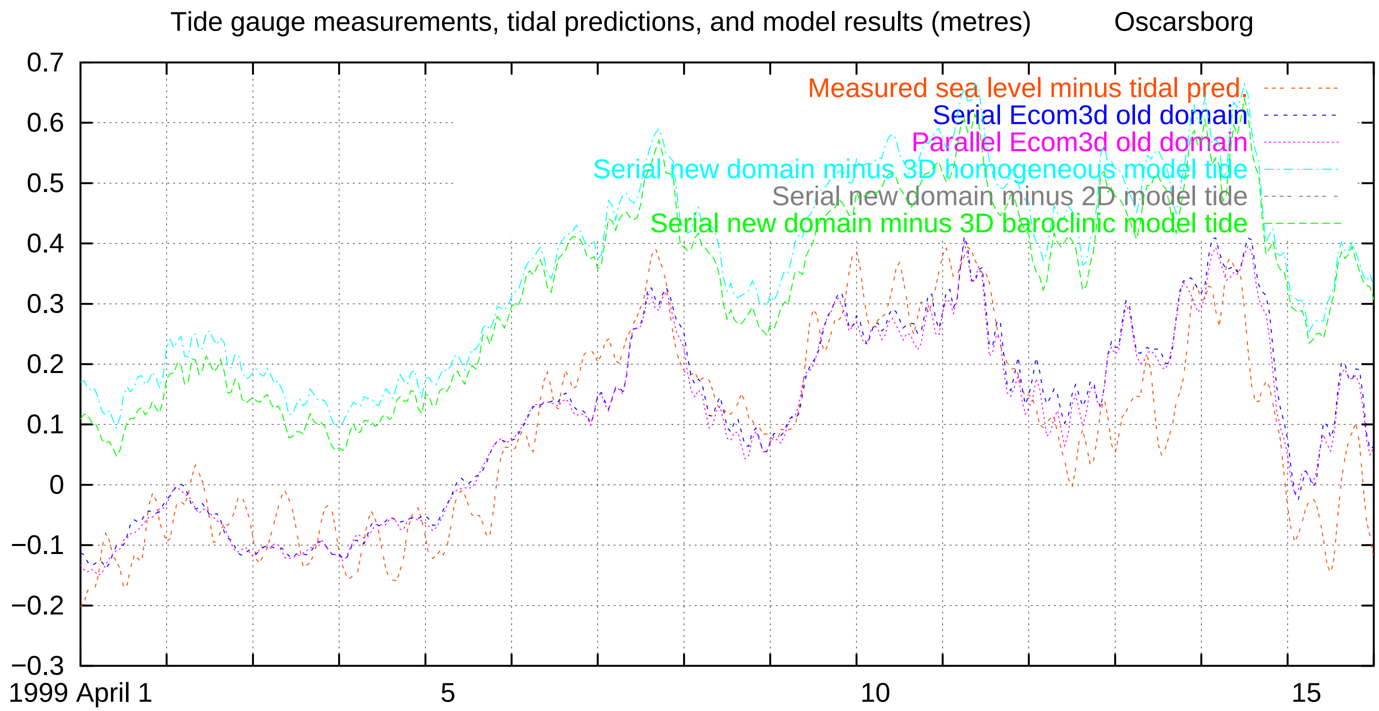

Fig. 29. Measured and modelled water level, excluding tides, Oscarsborg, 1999 April 1–15

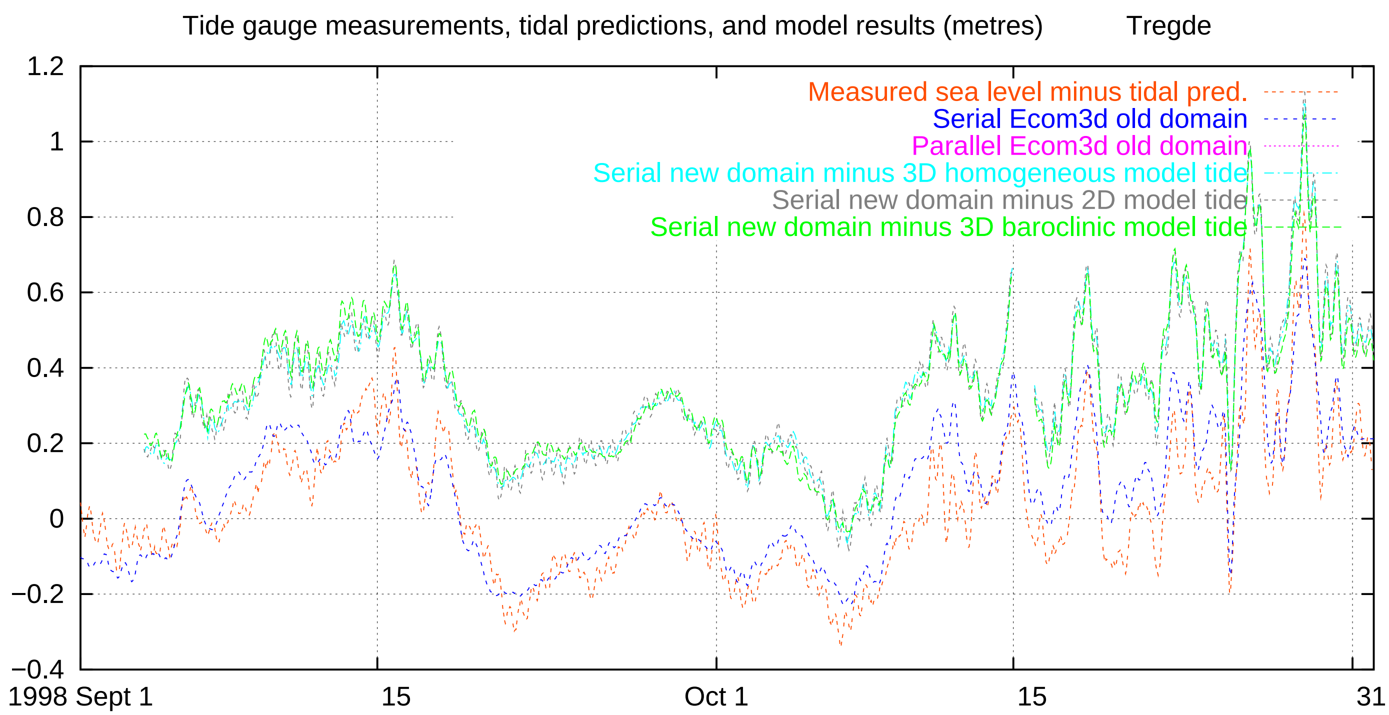

Fig. 30. Measured and modelled water level, excluding tides, Tregde, 1998 September–October

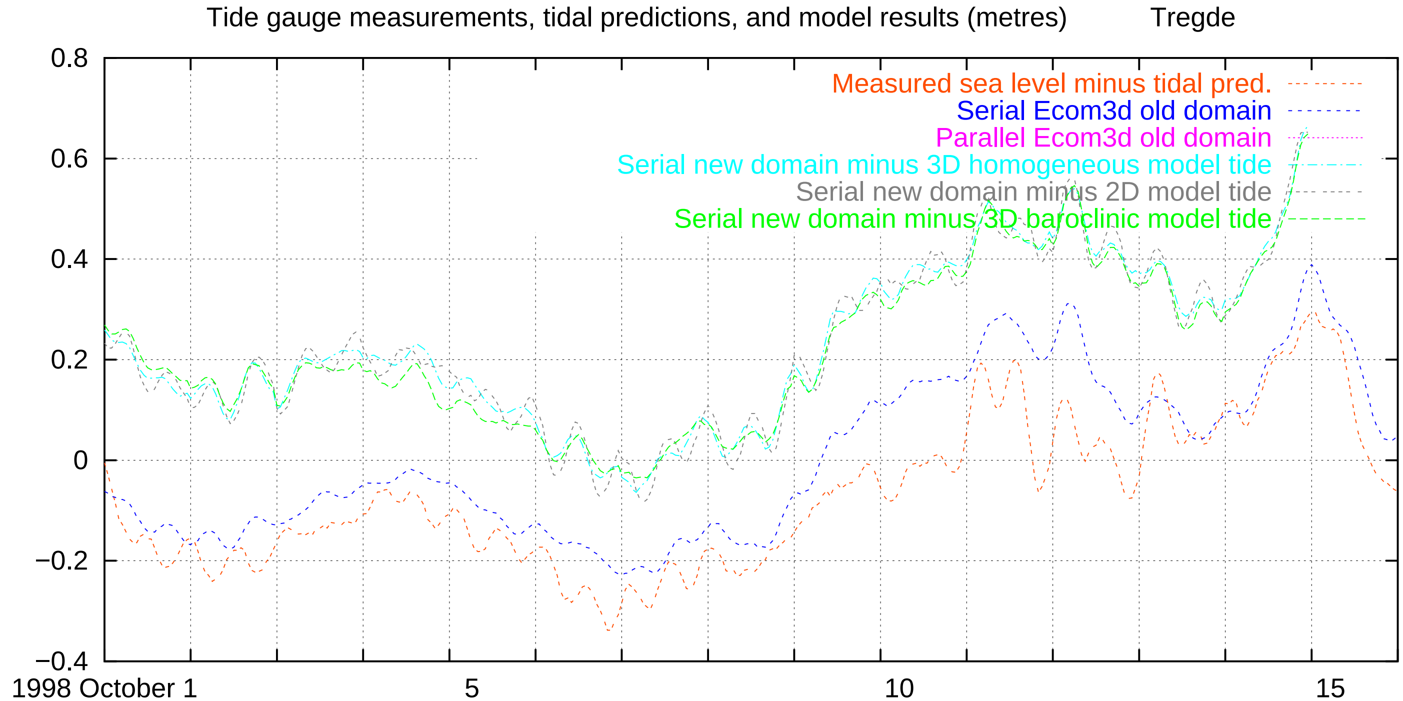

Fig. 31. Measured and modelled water level, excluding tides, Tregde, 1998 October 1–15

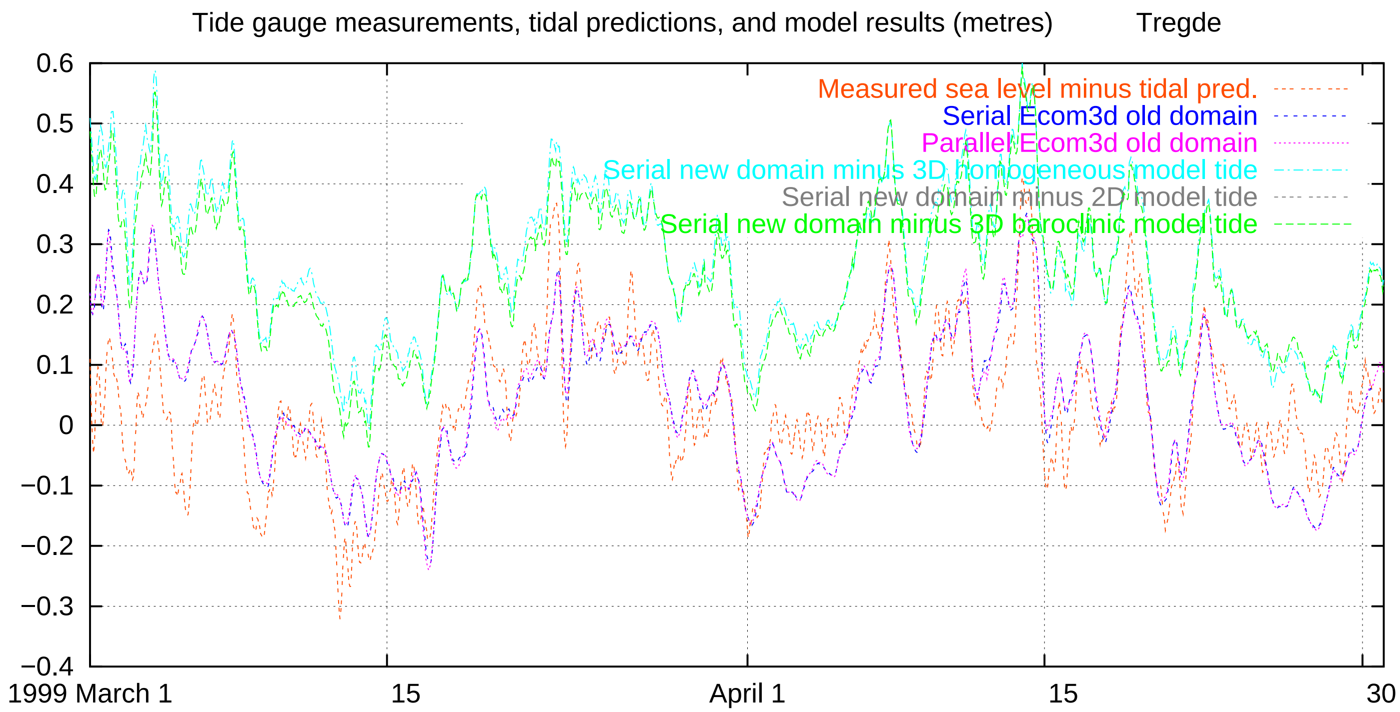

Fig. 32. Measured and modelled water level, excluding tides, Tregde, 1999 March–April

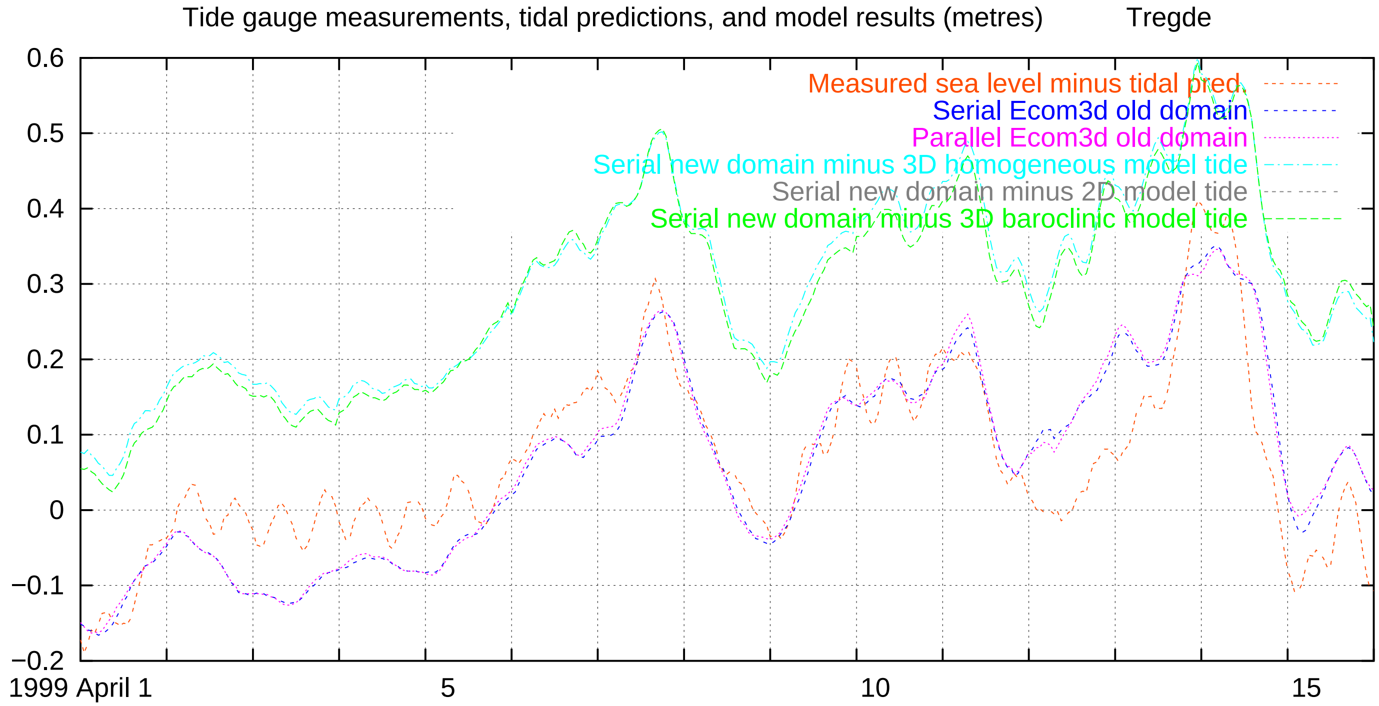

Fig. 33. Measured and modelled water level, excluding tides, Tregde, 1999 April 1–15

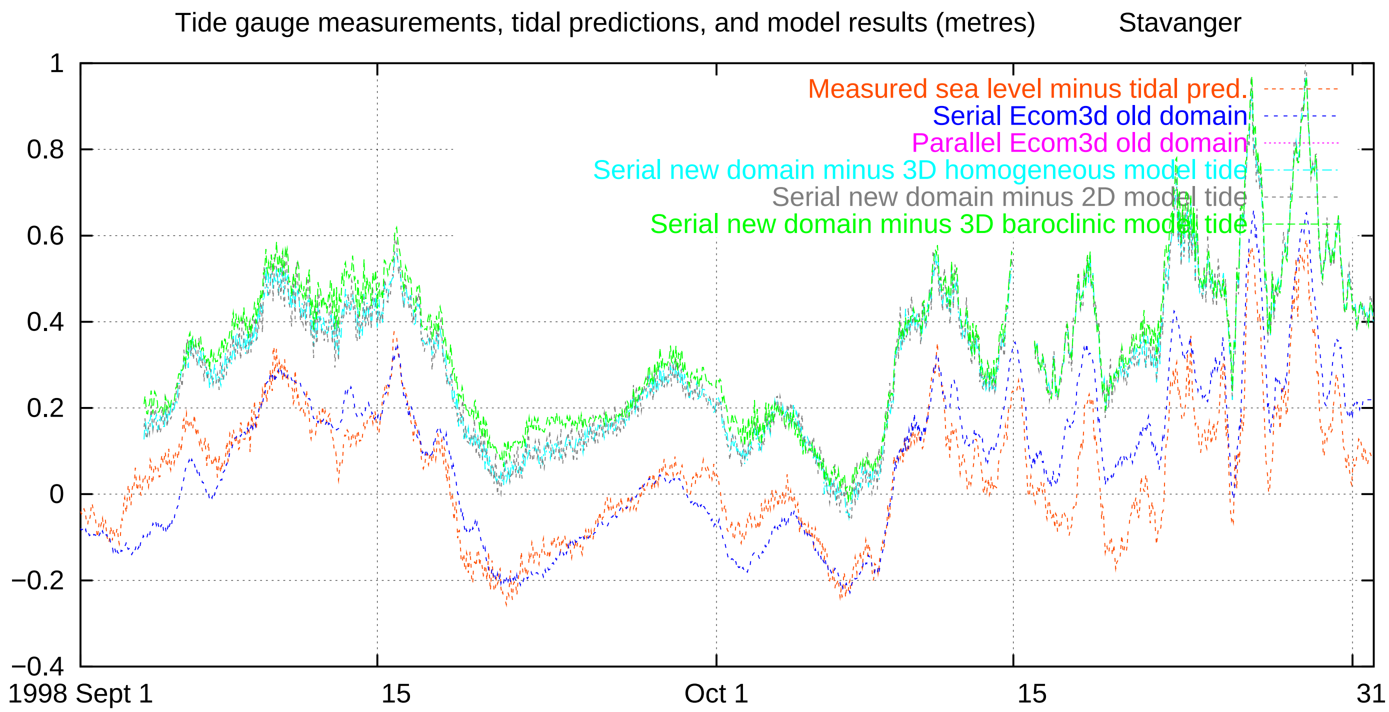

Fig. 34. Measured and modelled water level, excluding tides, Stavanger, 1998 September–October

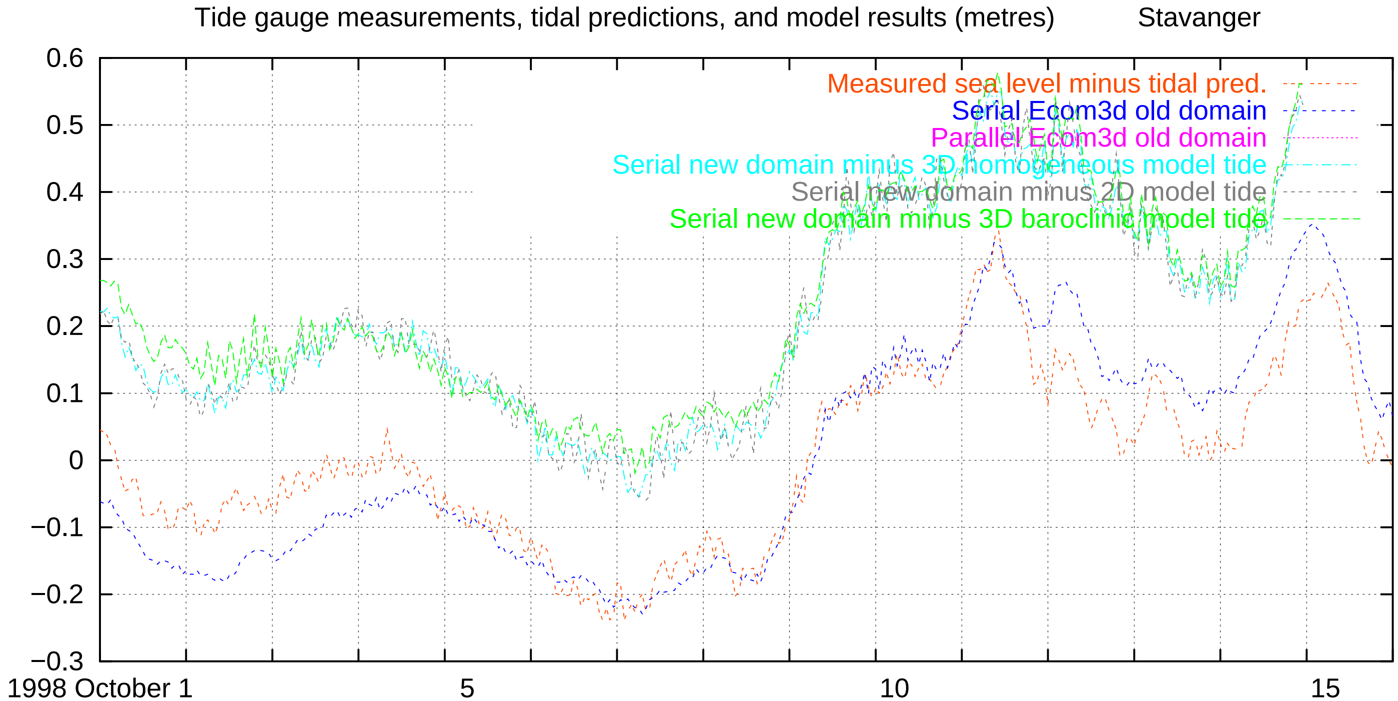

Fig. 35. Measured and modelled water level, excluding tides, Stavanger, 1998 October 1–15

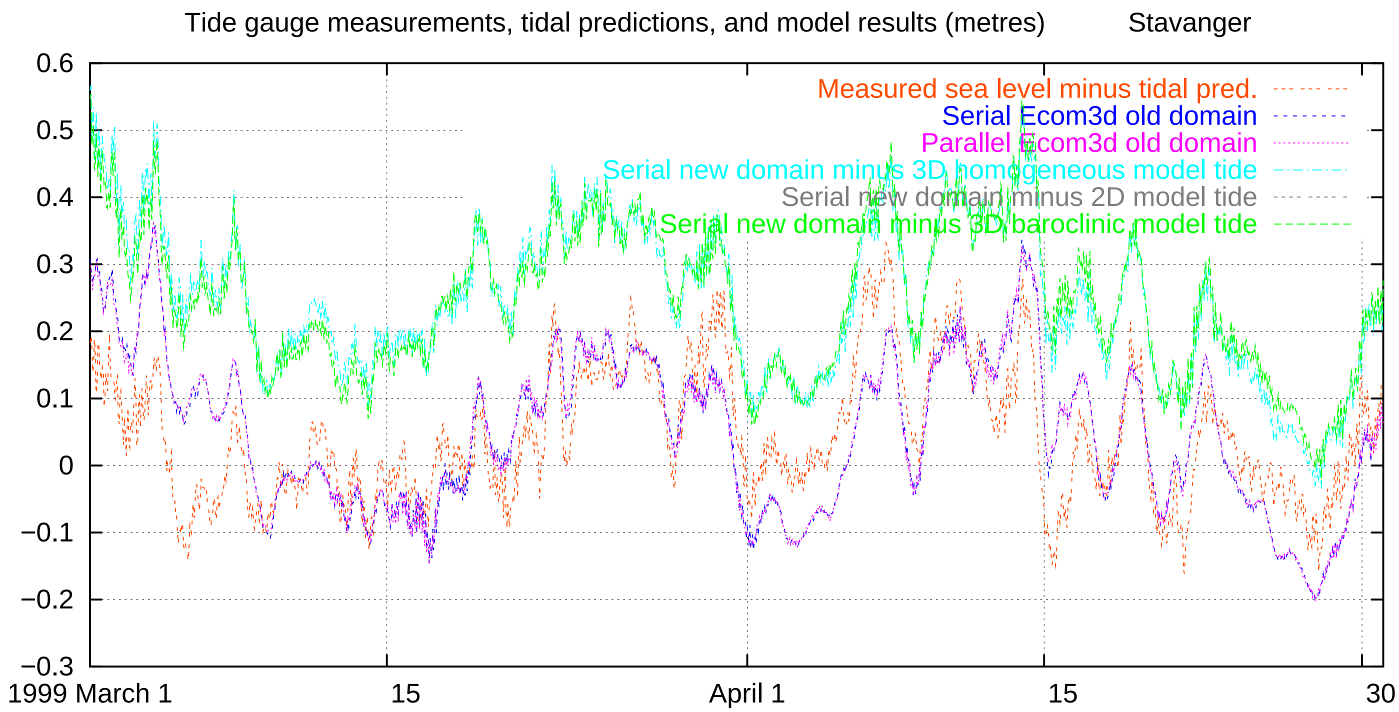

Fig. 36. Measured and modelled water level, excluding tides, Stavanger, 1999 March–April

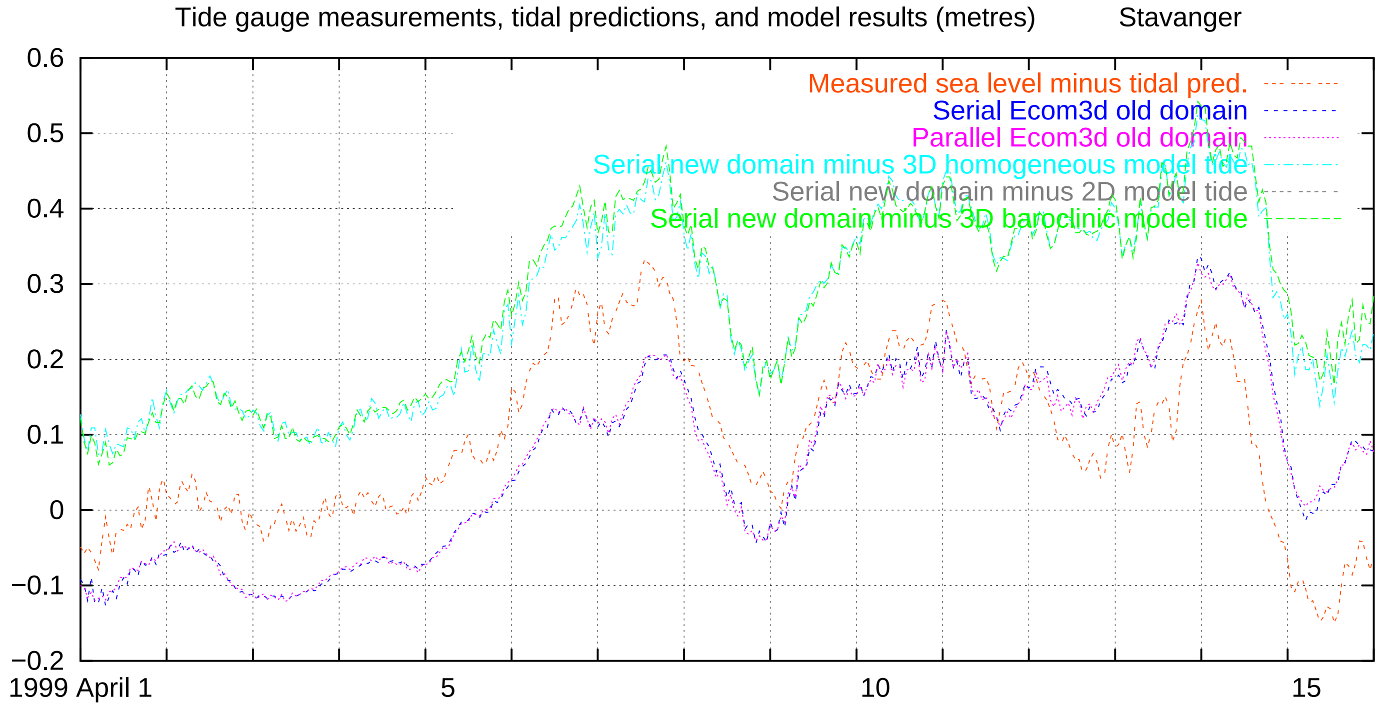

Fig. 37. Measured and modelled water level, excluding tides, Stavanger, 1999 April 1–15

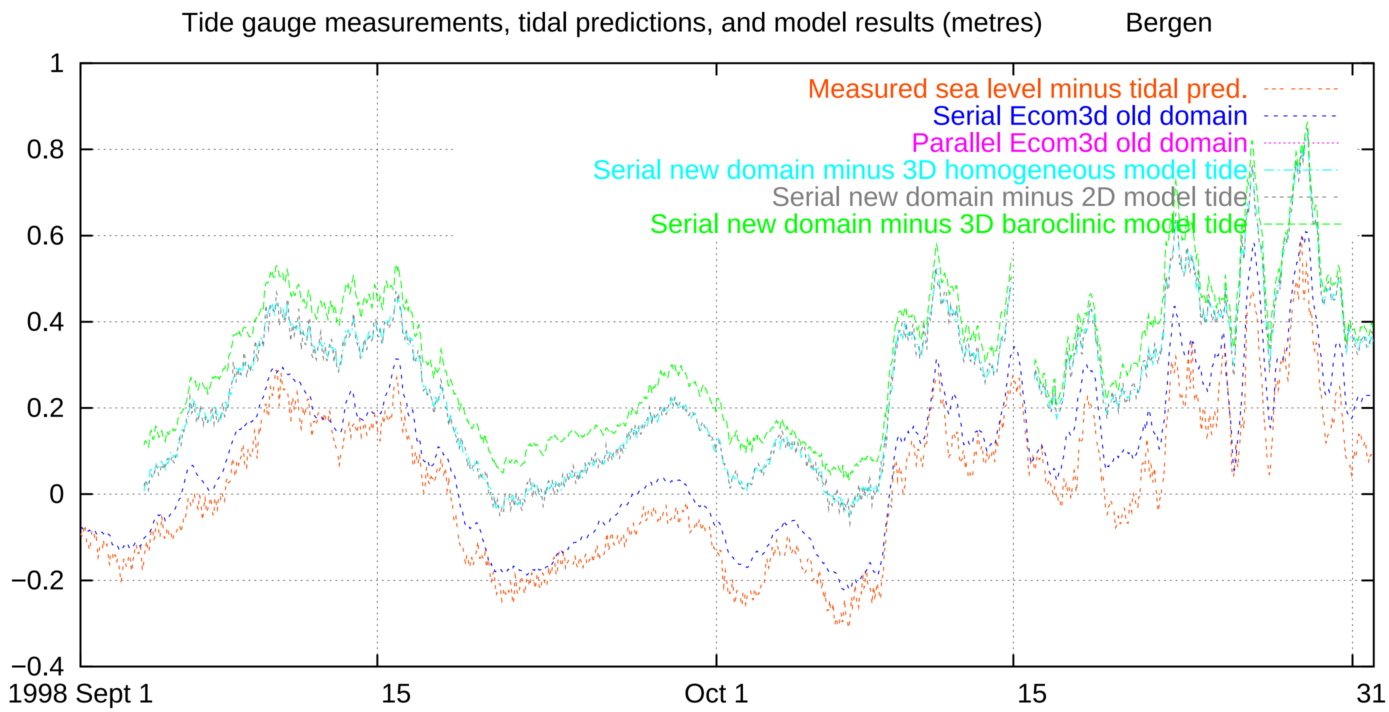

Fig. 38. Measured and modelled water level, excluding tides, Bergen, 1998 September–October

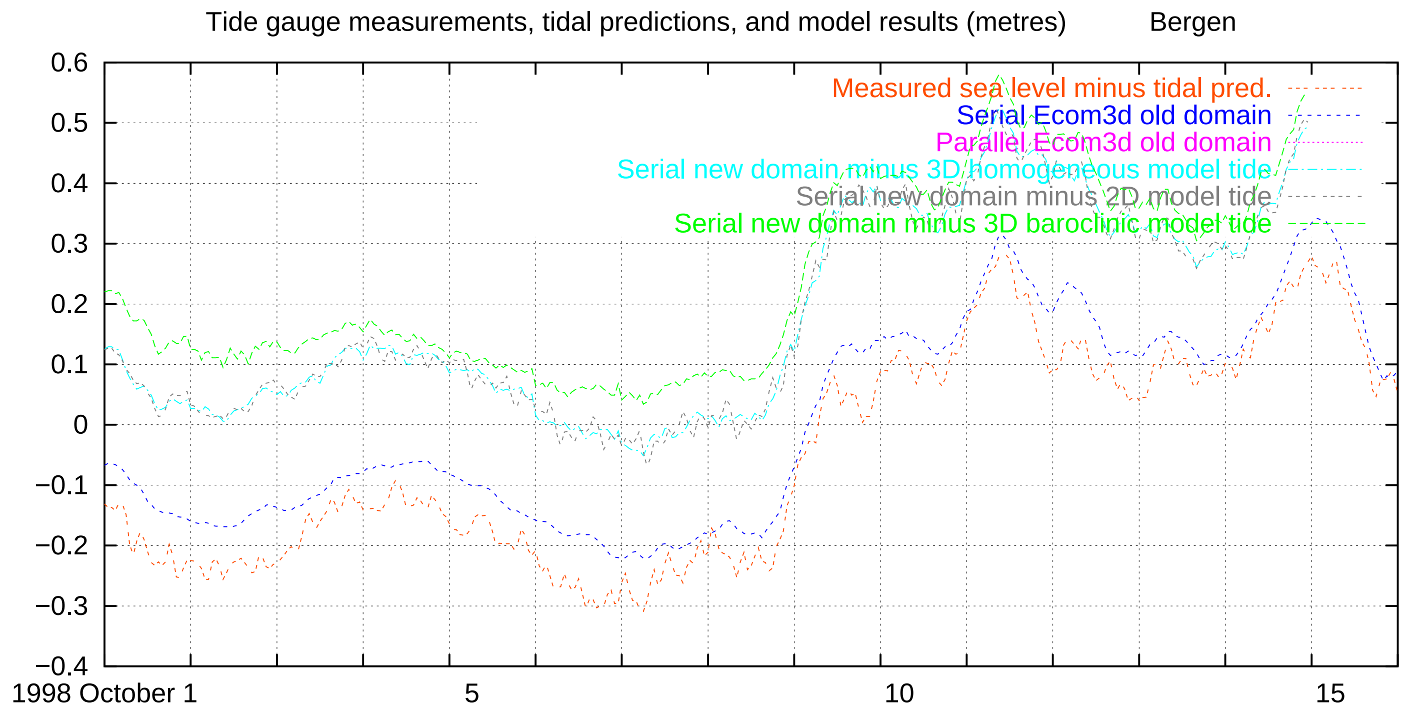

Fig. 39. Measured and modelled water level, excluding tides, Bergen, 1998 October 1–15

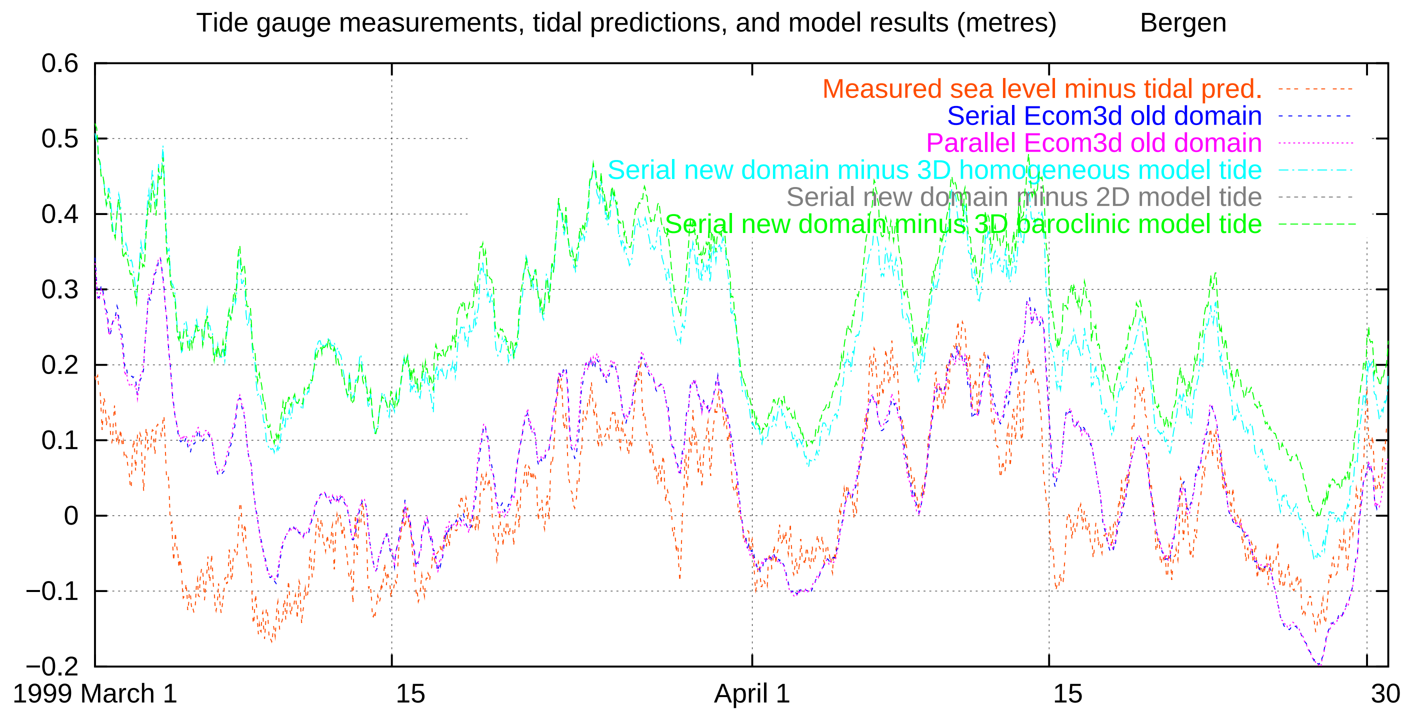

Fig. 40. Measured and modelled water level, excluding tides, Bergen, 1999 March–April

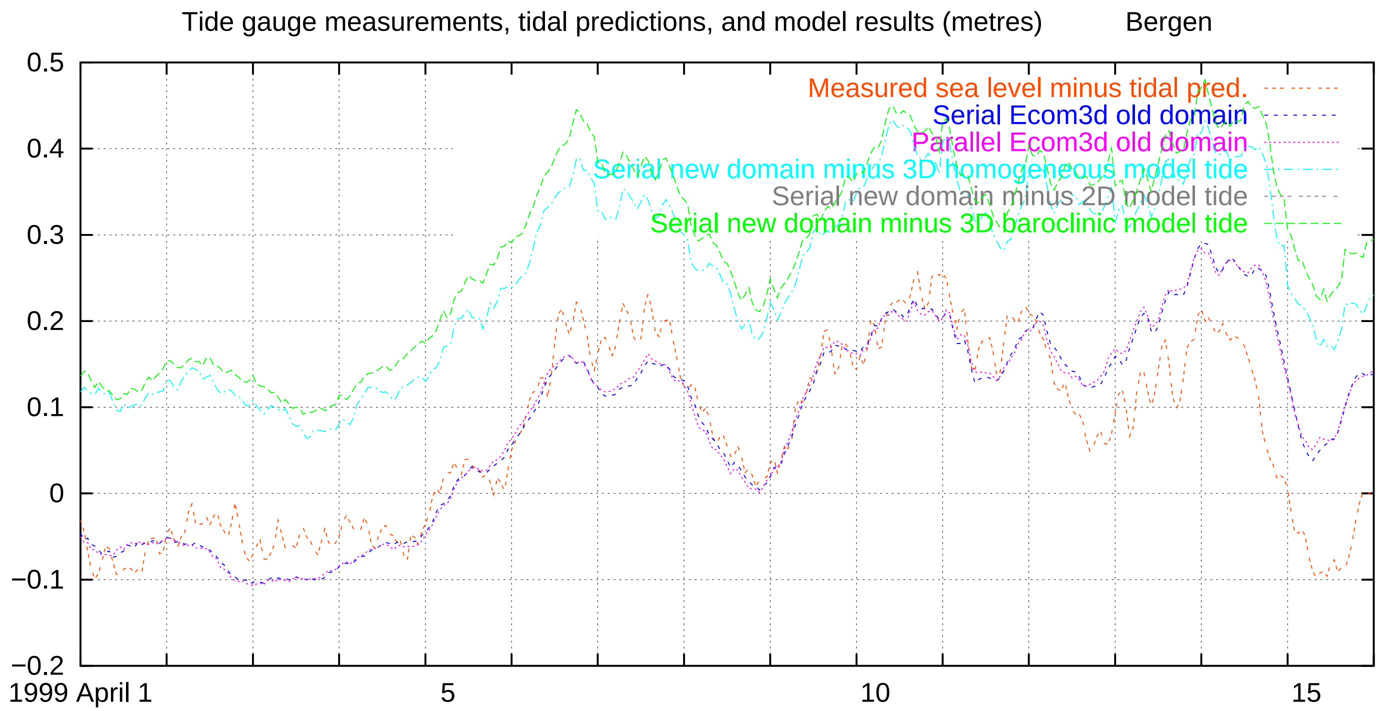

Fig. 41. Measured and modelled water level, excluding tides, Bergen, 1999 April 1–15

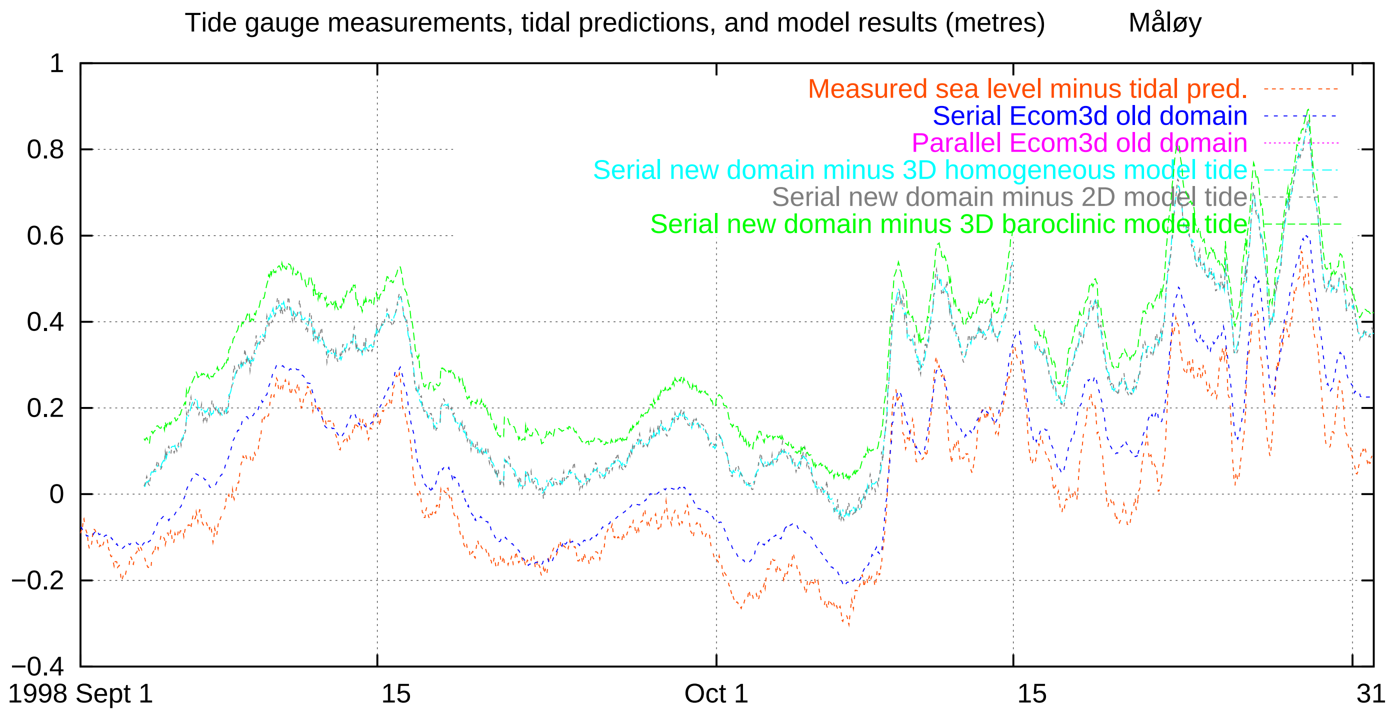

Fig. 42. Measured and modelled water level, excluding tides, Måløy, 1998 September–October

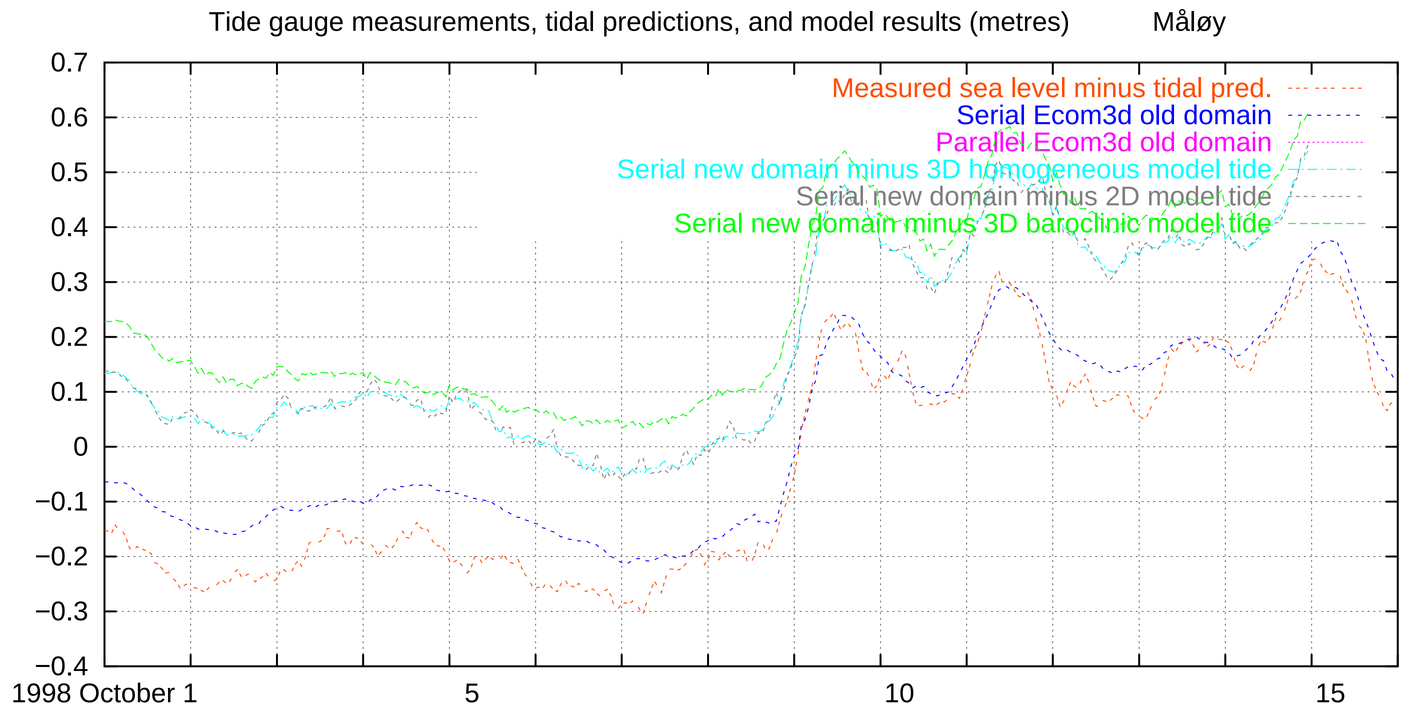

Fig. 43. Measured and modelled water level, excluding tides, Måløy, 1998 October 1–15

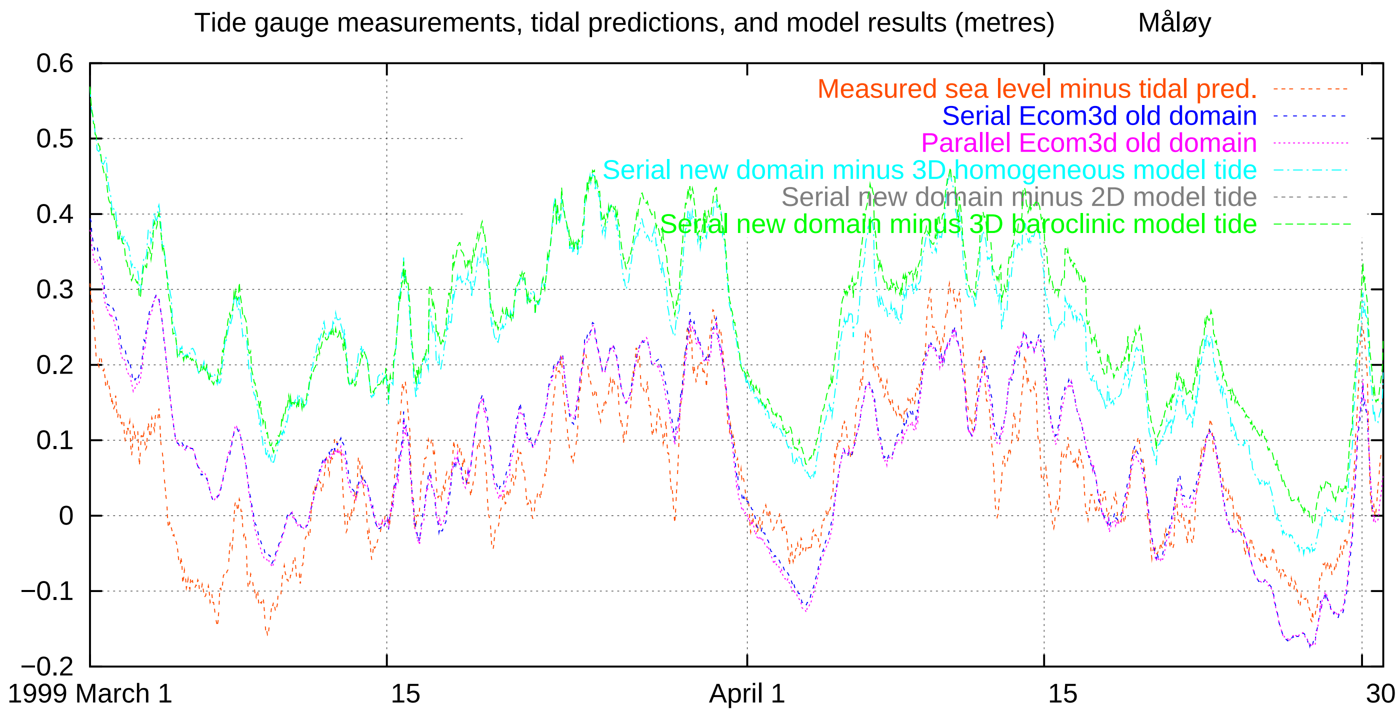

Fig. 44. Measured and modelled water level, excluding tides, Måløy, 1999 March–April

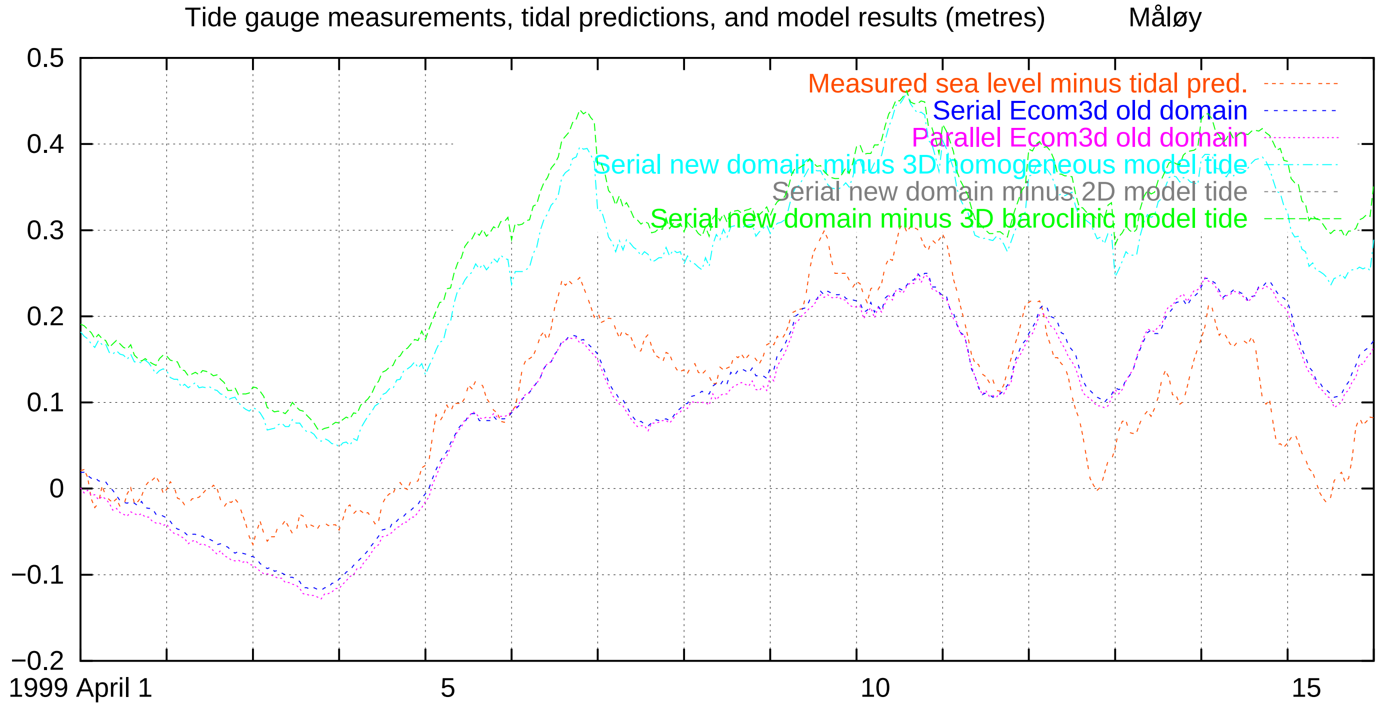

Fig. 45. Measured and modelled water level, excluding tides, Måløy, 1999 April 1–15

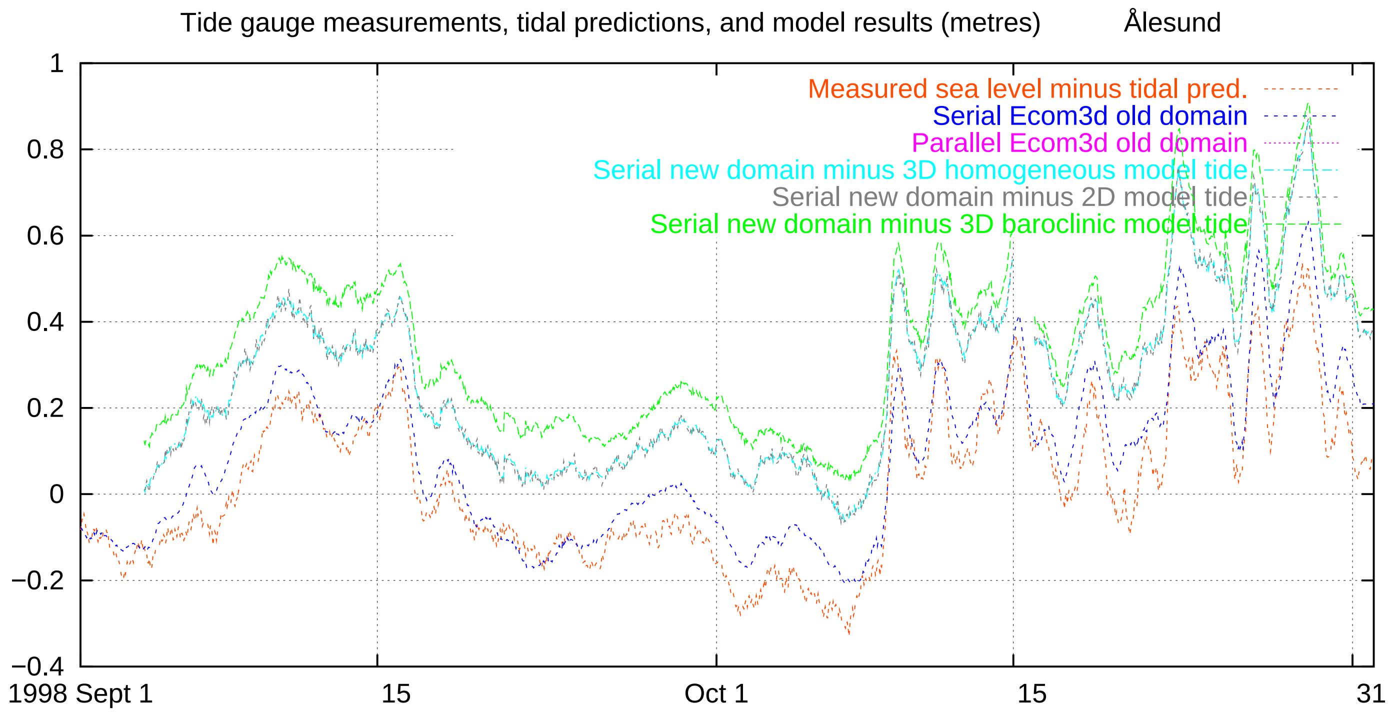

Fig. 46. Measured and modelled water level, excluding tides, Ålesund, 1998 September–October

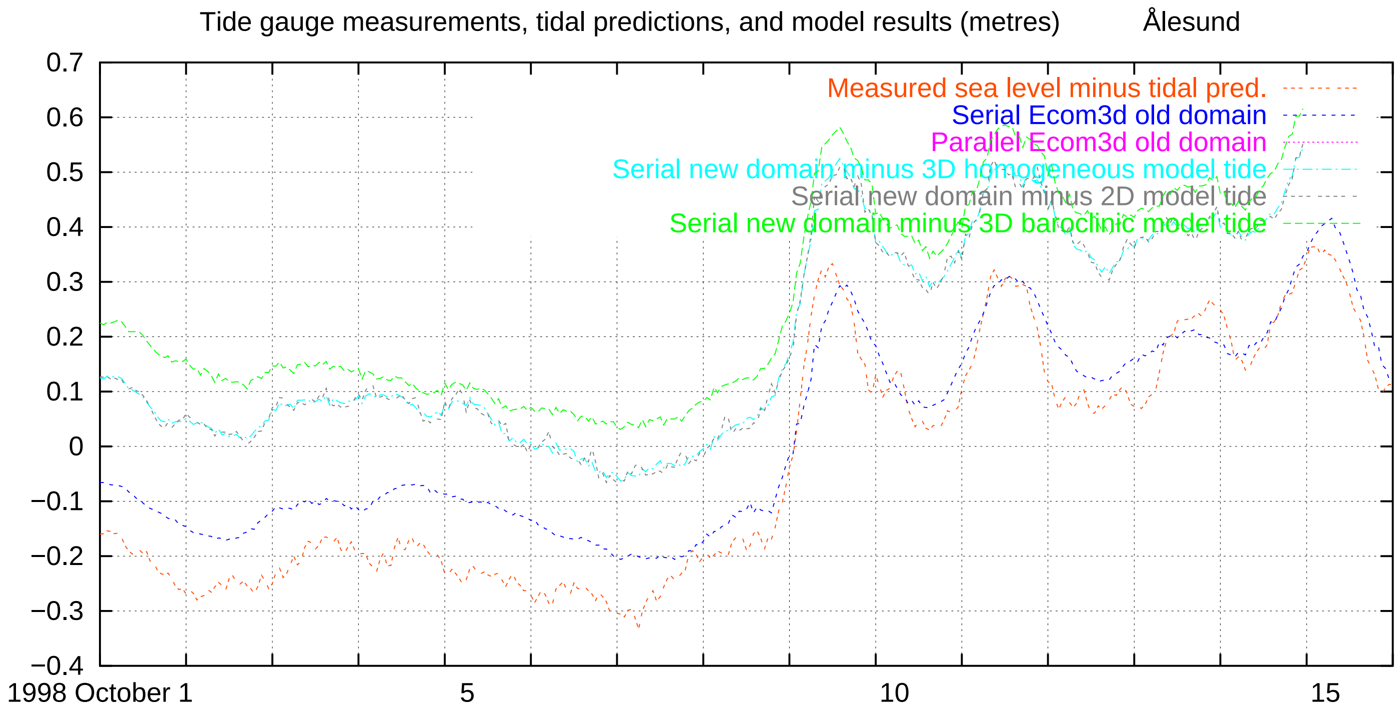

Fig. 47. Measured and modelled water level, excluding tides, Ålesund, 1998 October 1–15

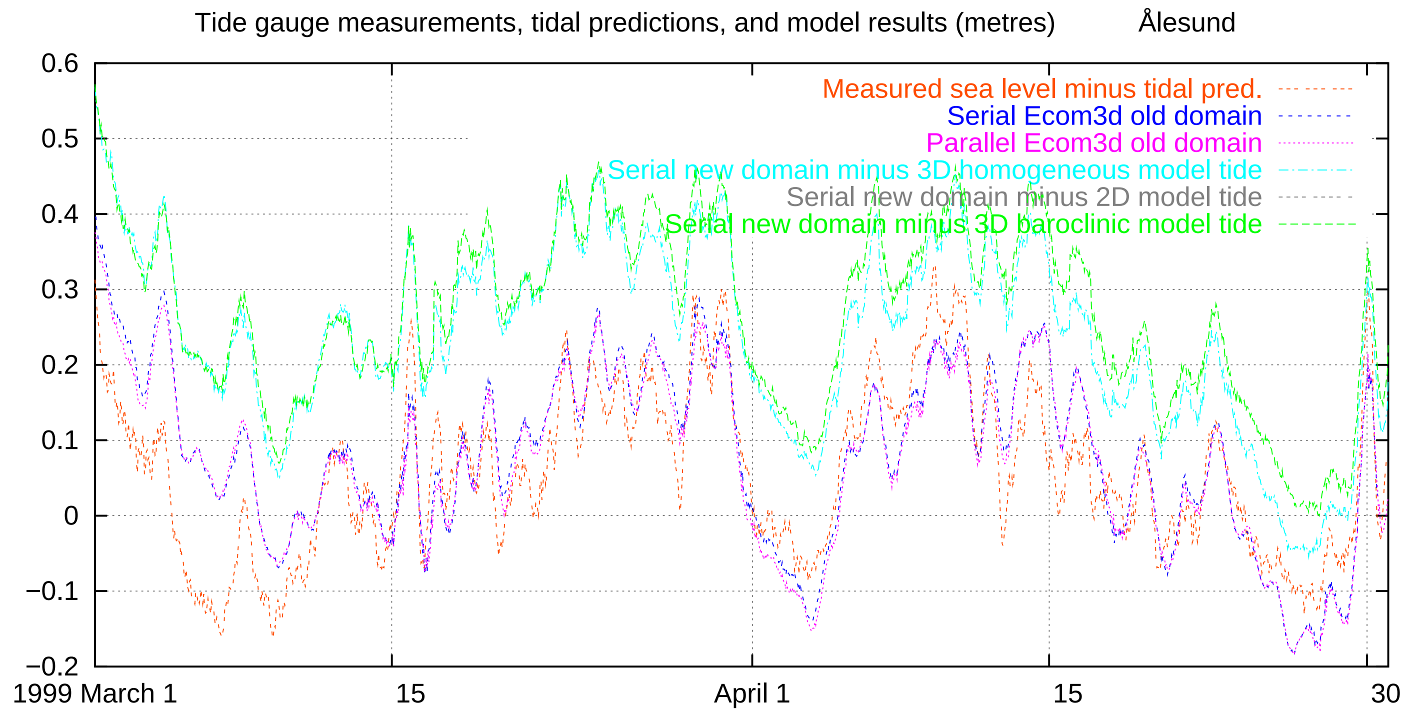

Fig. 48. Measured and modelled water level, excluding tides, Ålesund, 1999 March–April

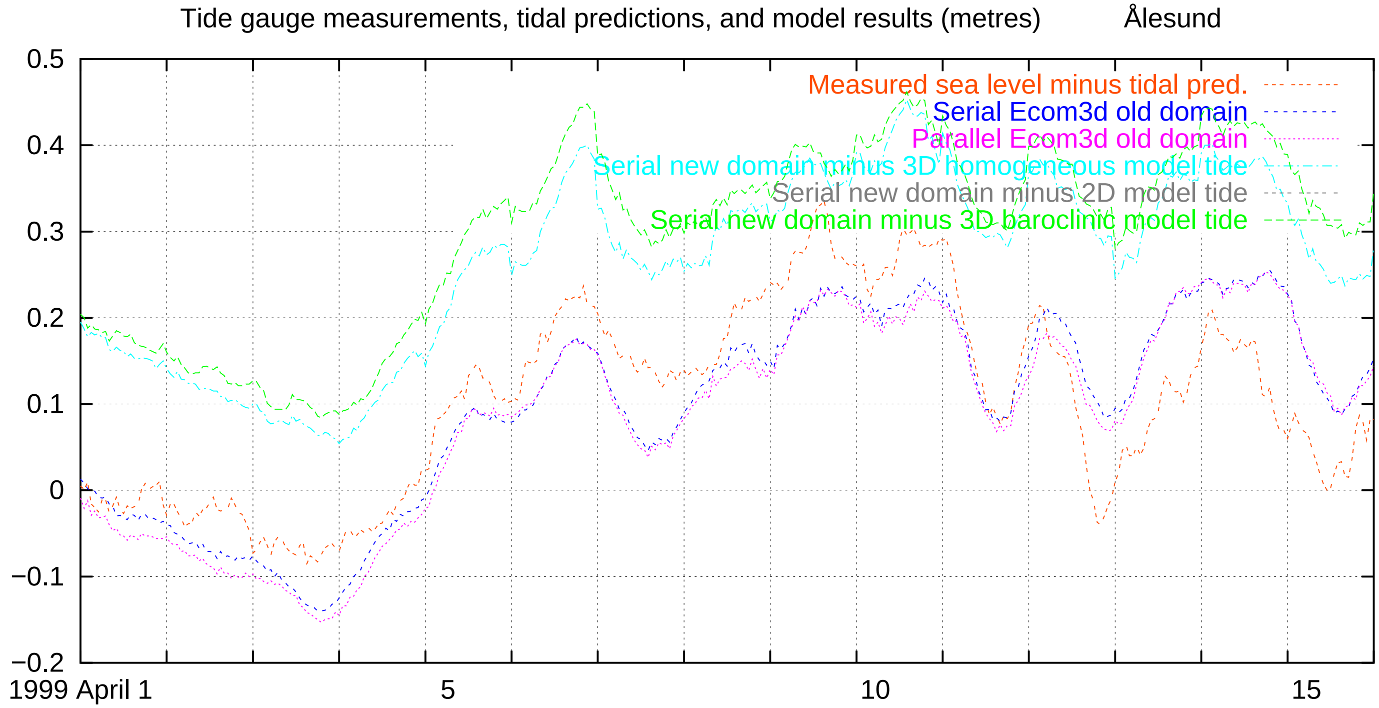

Fig. 49. Measured and modelled water level, excluding tides, Ålesund, 1999 April 1–15

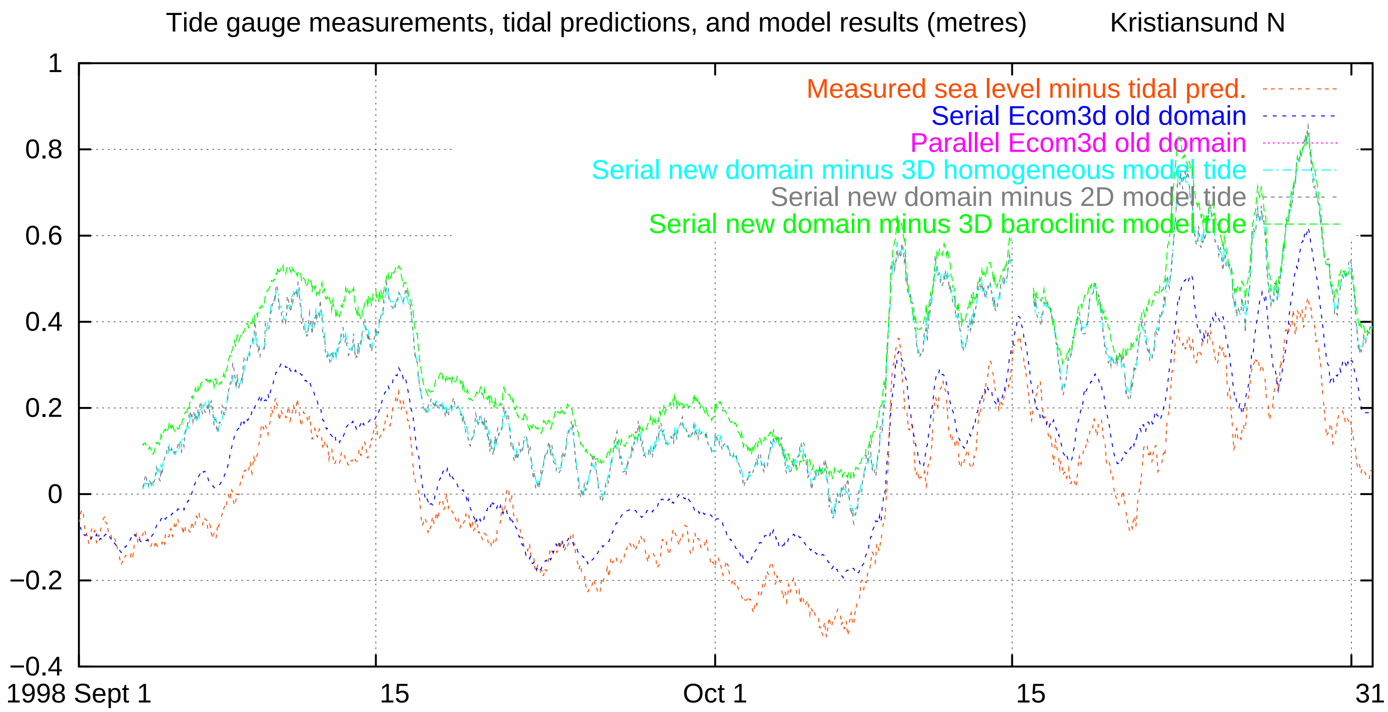

Fig. 50. Measured and modelled water level, excluding tides, Kristiansund N, 1998 September–October

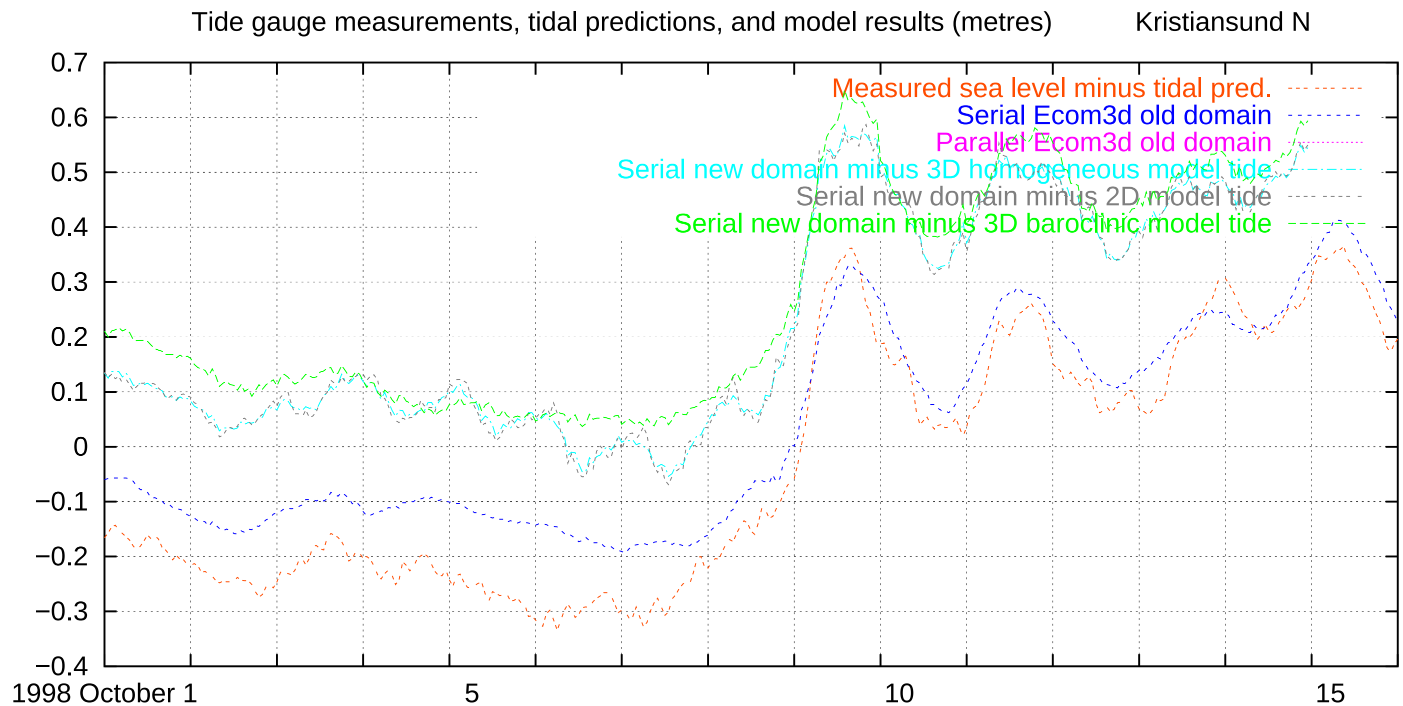

Fig. 51. Measured and modelled water level, excluding tides, Kristiansund N, 1998 October 1–15

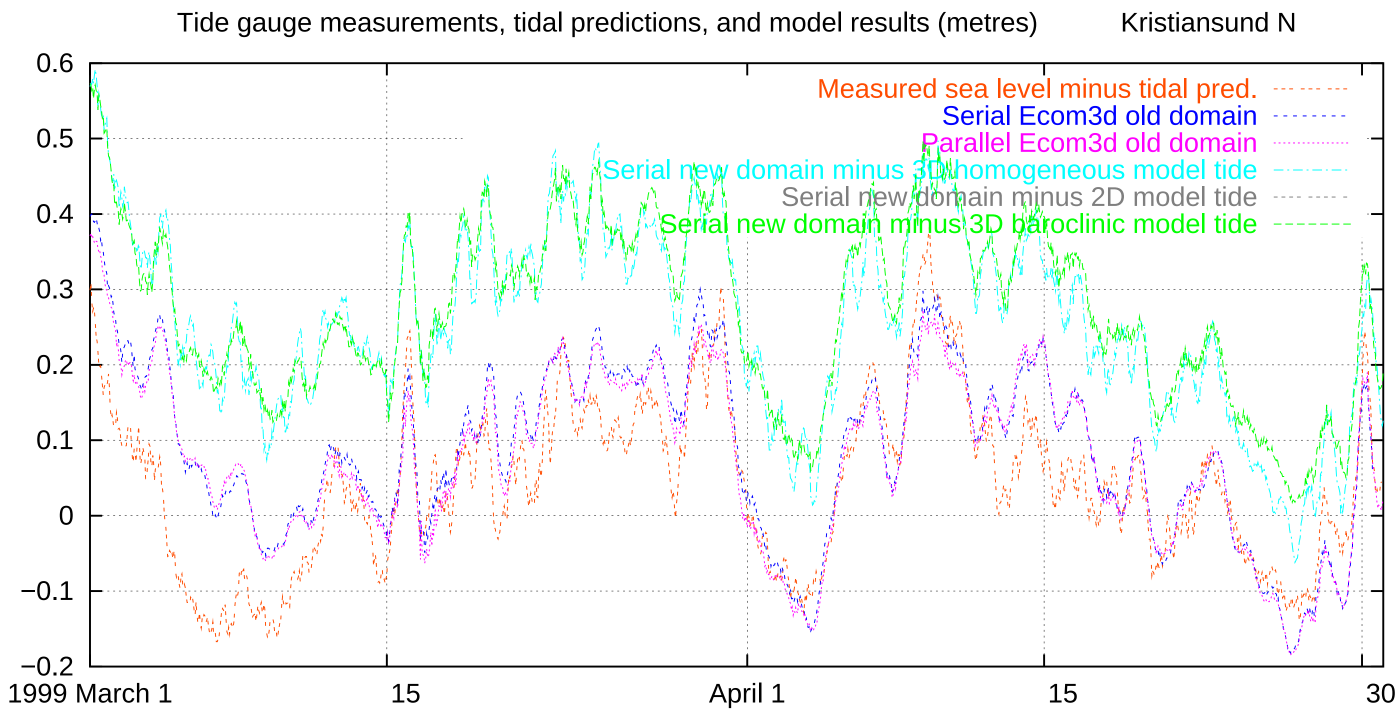

Fig. 52. Measured and modelled water level, excluding tides, Kristiansund N, 1999 March–April

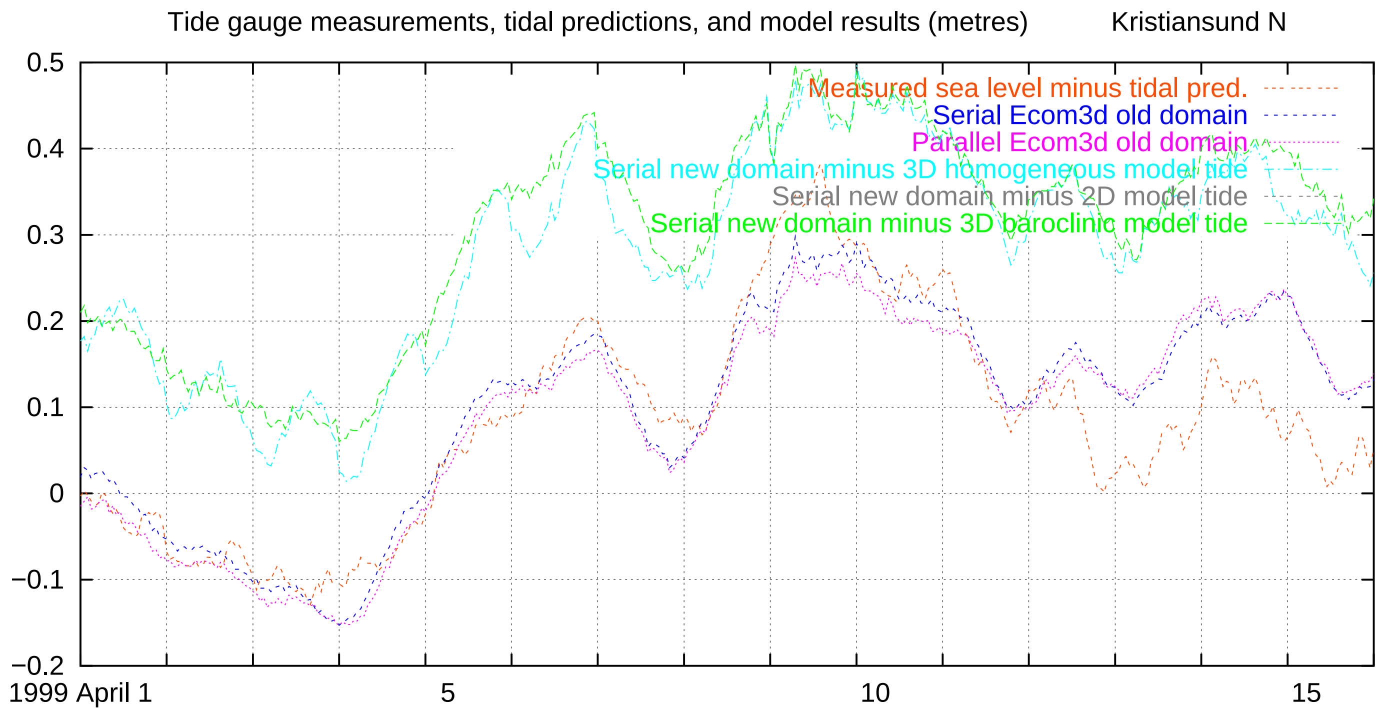

Fig. 53. Measured and modelled water level, excluding tides, Kristiansund N, 1999 April 1–15

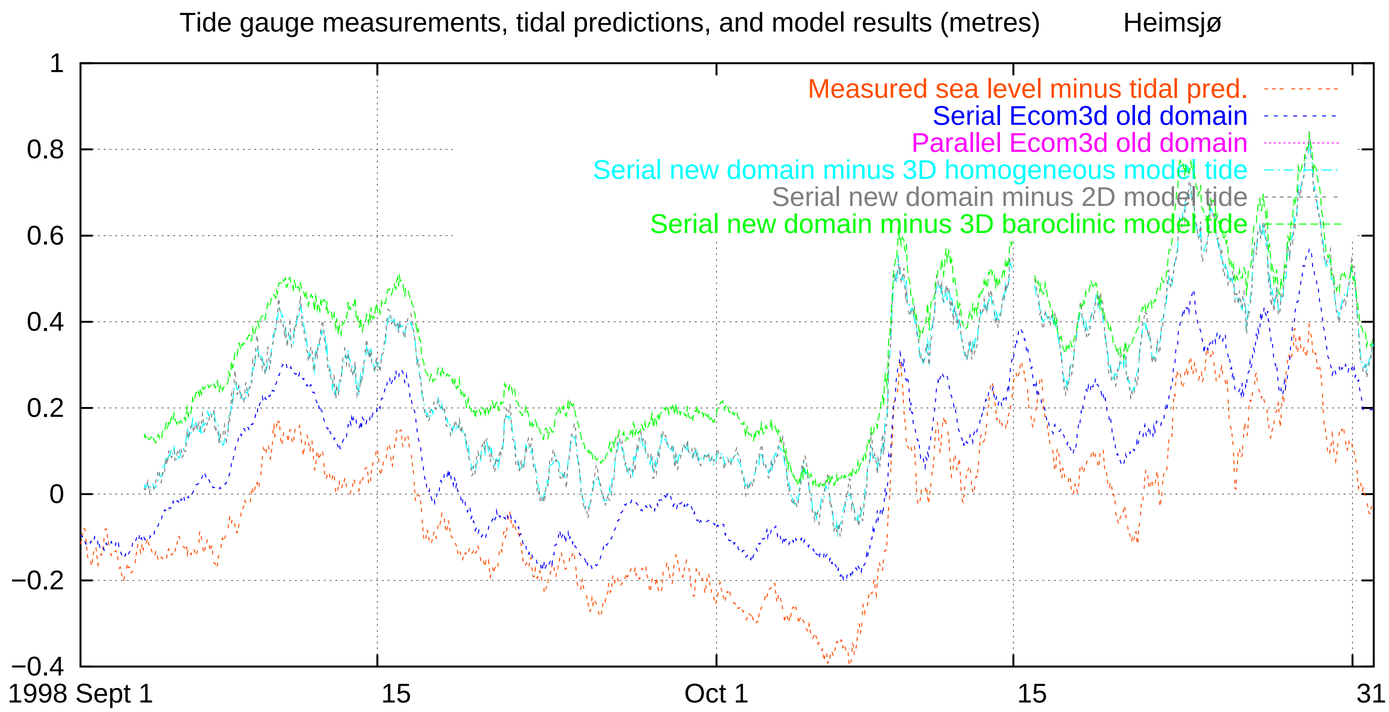

Fig. 54. Measured and modelled water level, excluding tides, Heimsjø, 1998 September–October

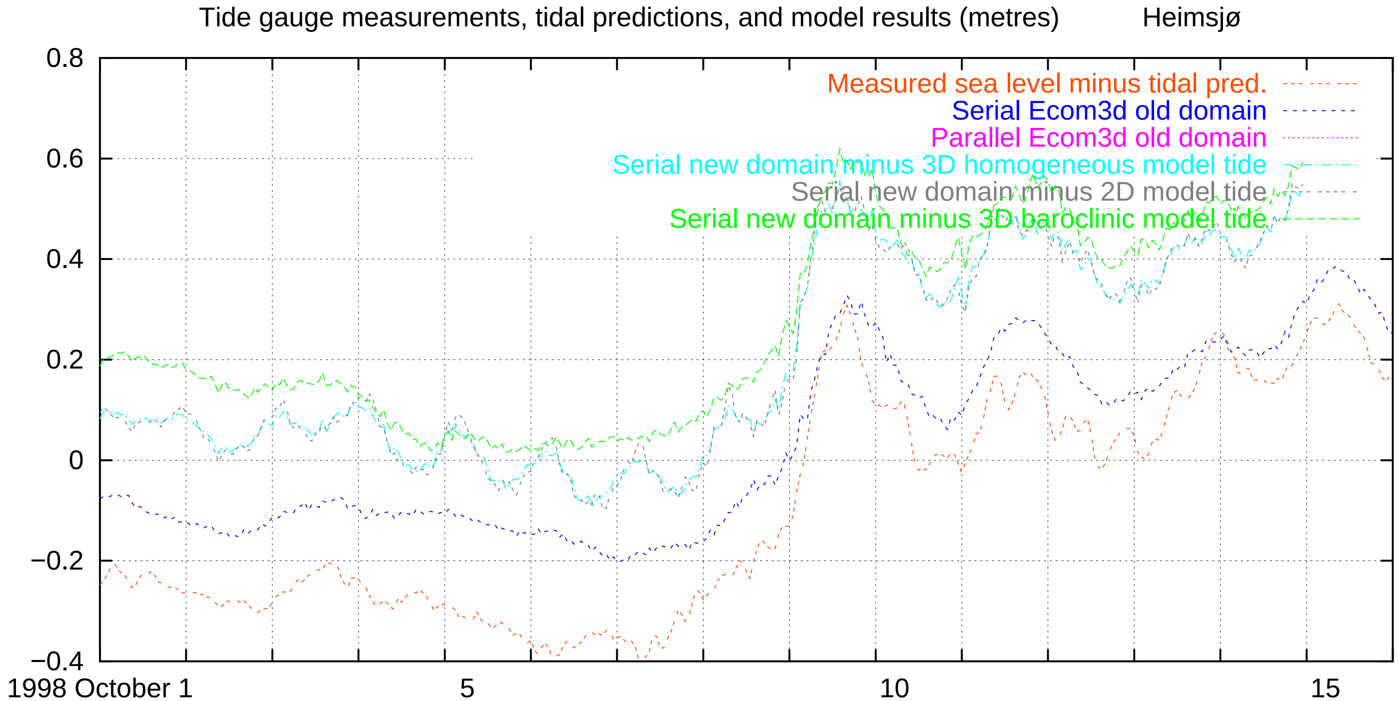

Fig. 55. Measured and modelled water level, excluding tides, Heimsjø, 1998 October 1–15

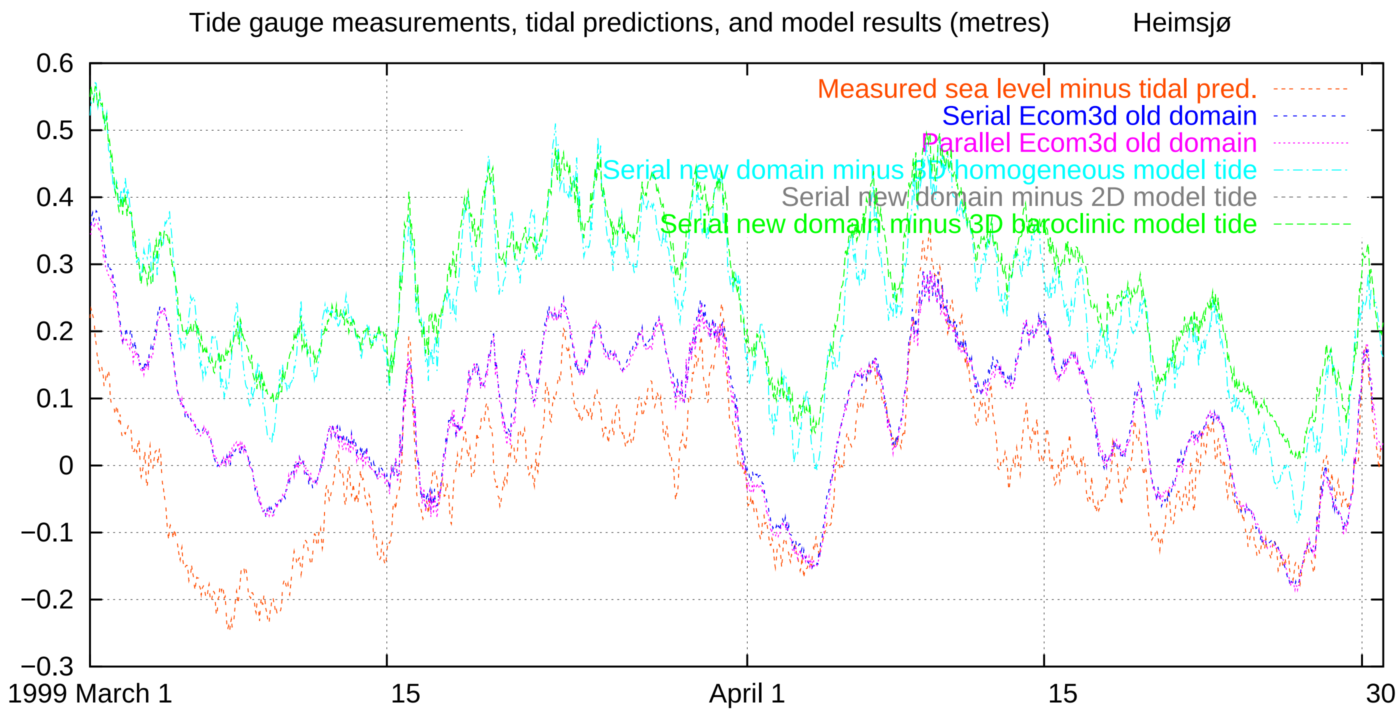

Fig. 56. Measured and modelled water level, excluding tides, Heimsjø, 1999 March–April

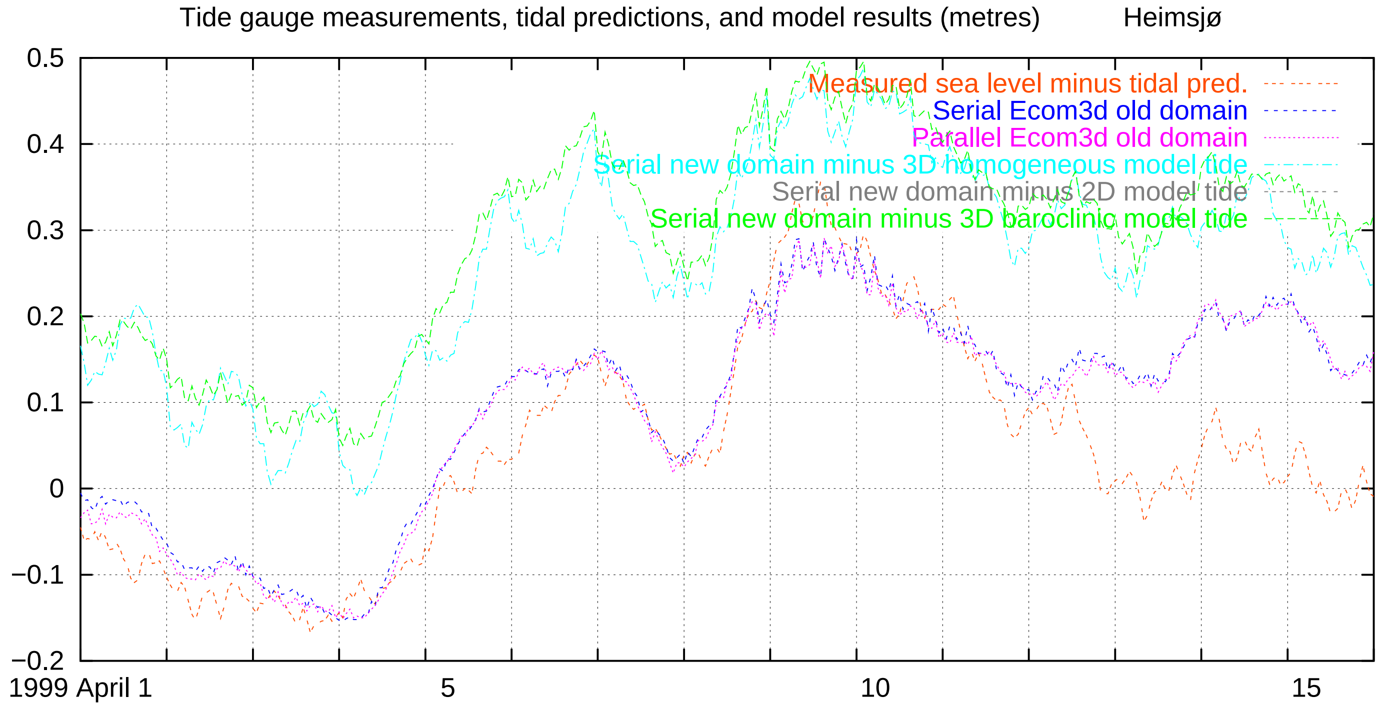

Fig. 57. Measured and modelled water level, excluding tides, Heimsjø, 1999 April 1–15

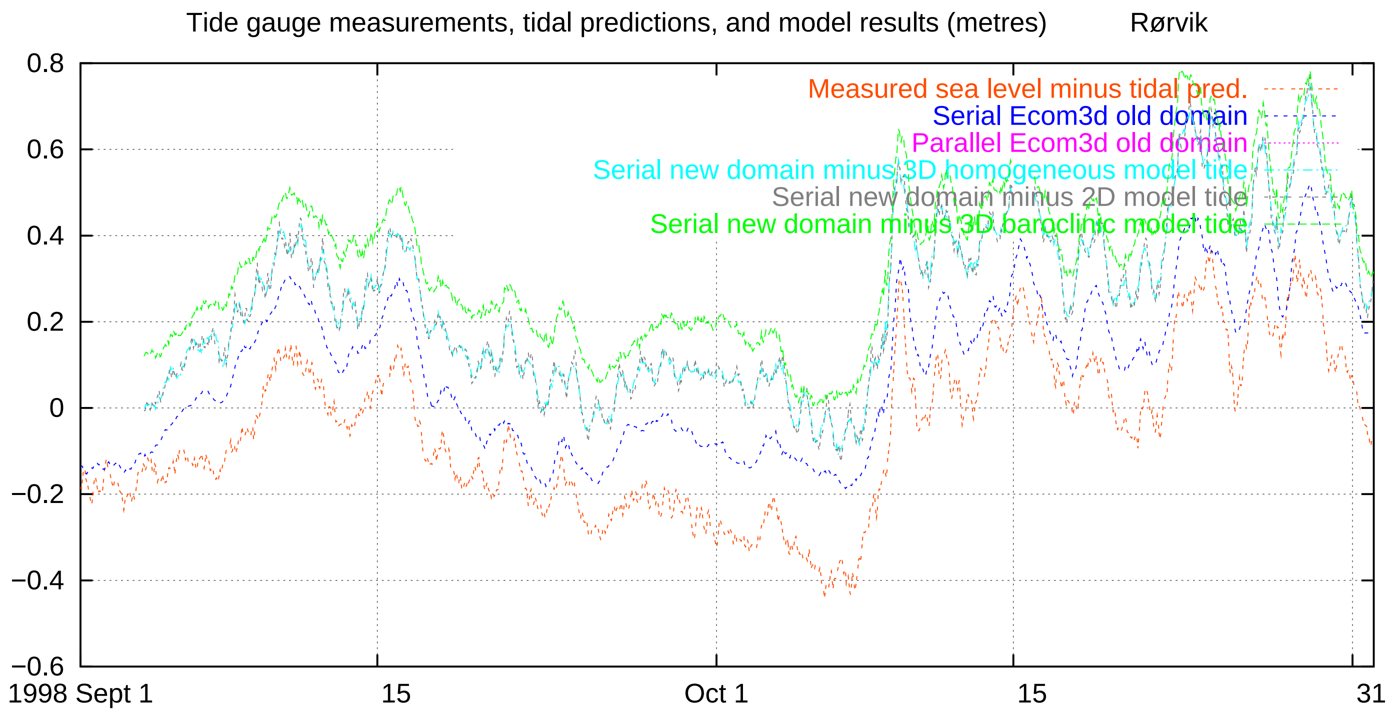

Fig. 58. Measured and modelled water level, excluding tides, Rørvik, 1998 September–October

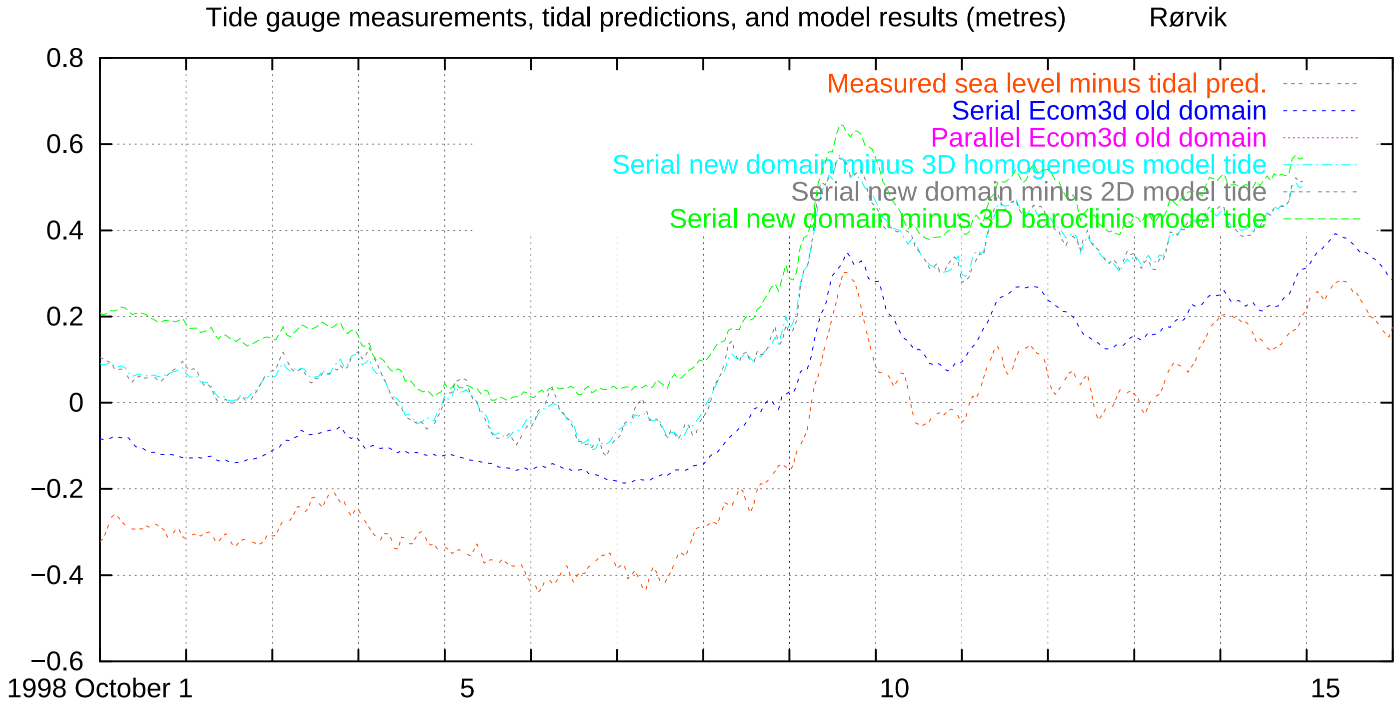

Fig. 59. Measured and modelled water level, excluding tides, Rørvik, 1998 October 1–15

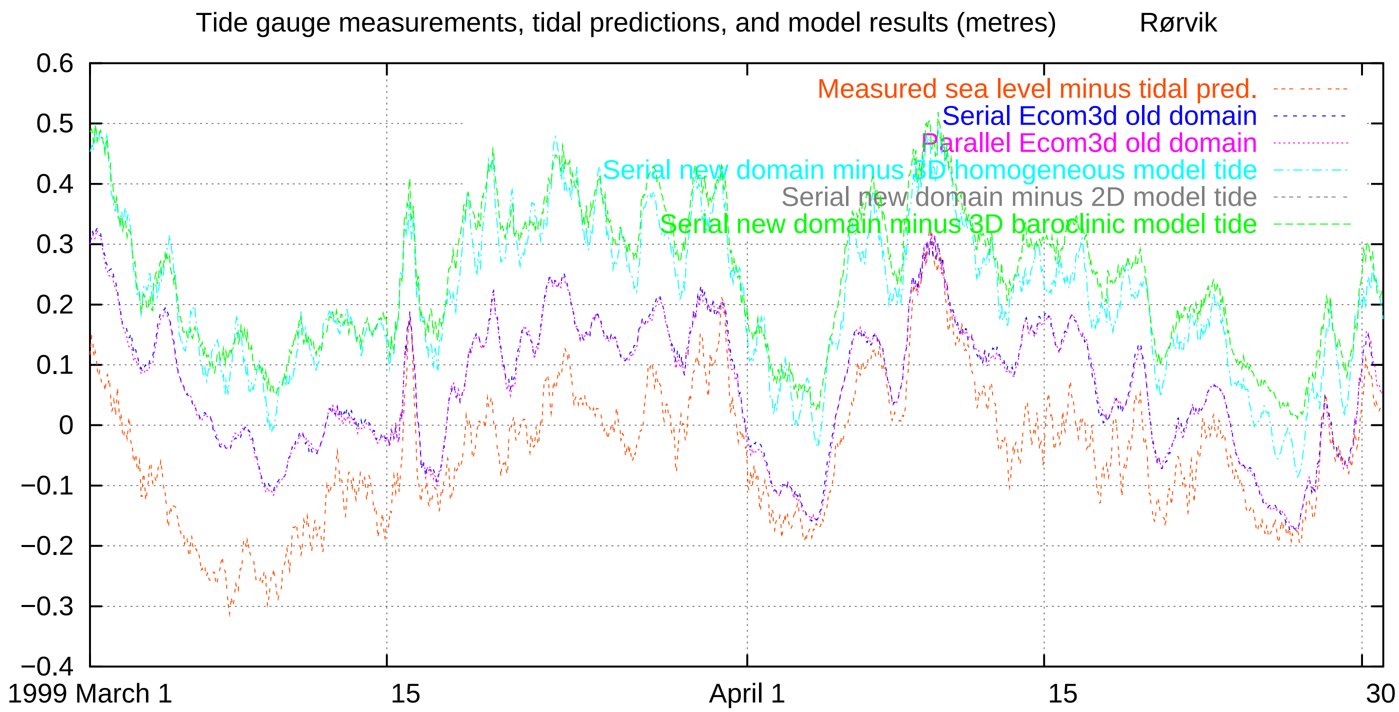

Fig. 60. Measured and modelled water level, excluding tides, Rørvik, 1999 March–April

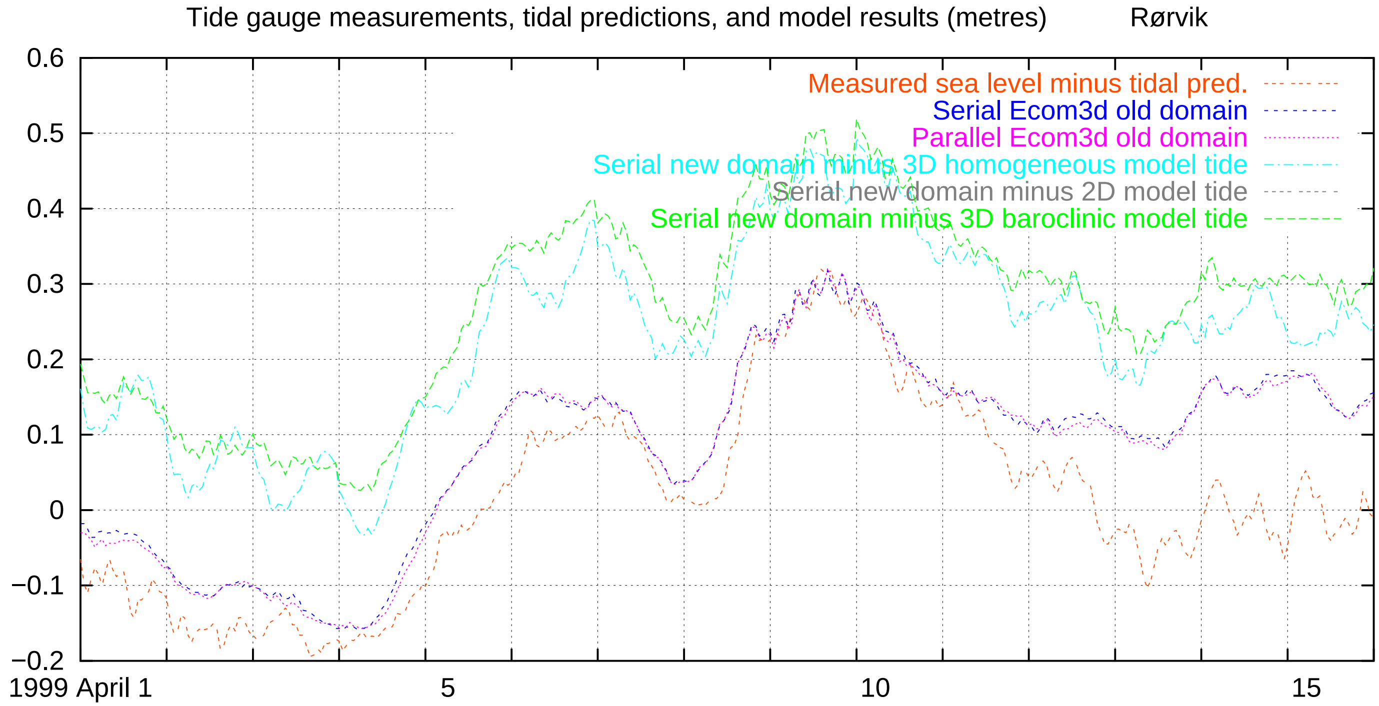

Fig. 61. Measured and modelled water level, excluding tides, Rørvik, 1999 April 1–15

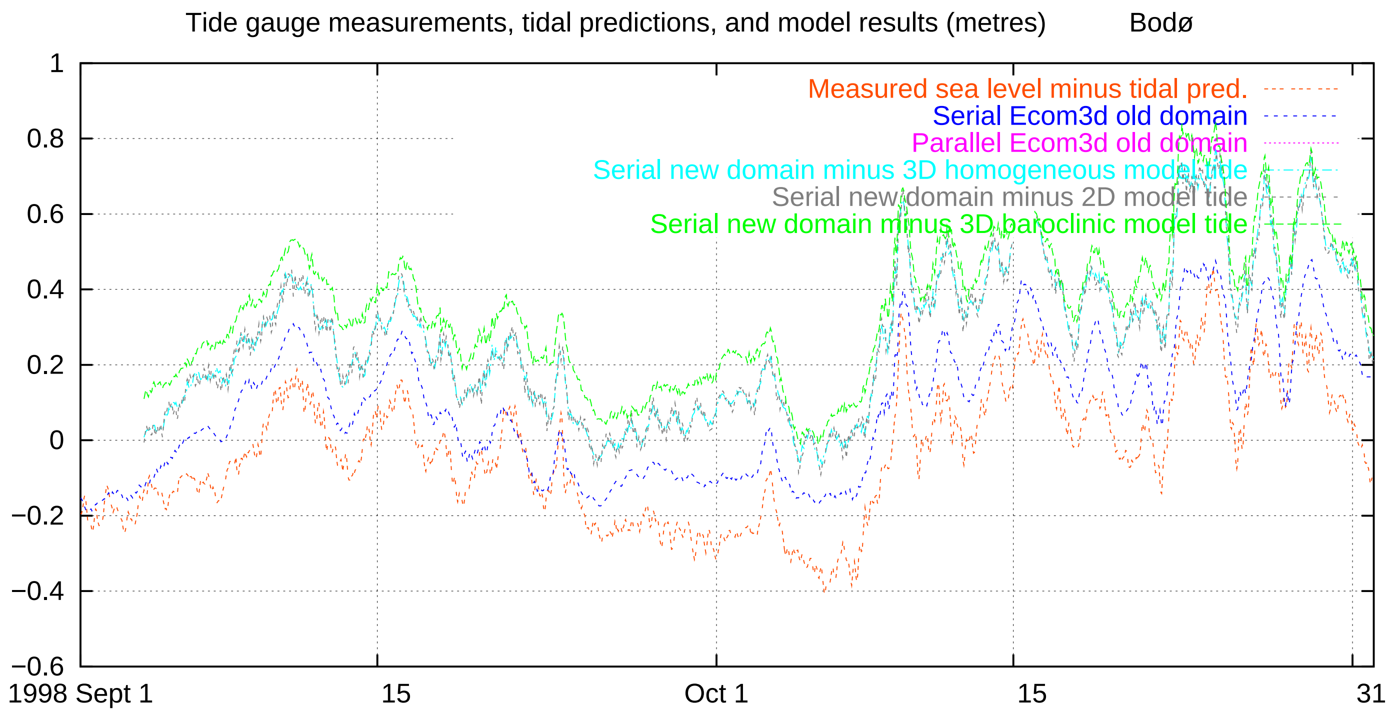

Fig. 62. Measured and modelled water level, excluding tides, Bodø, 1998 September–October

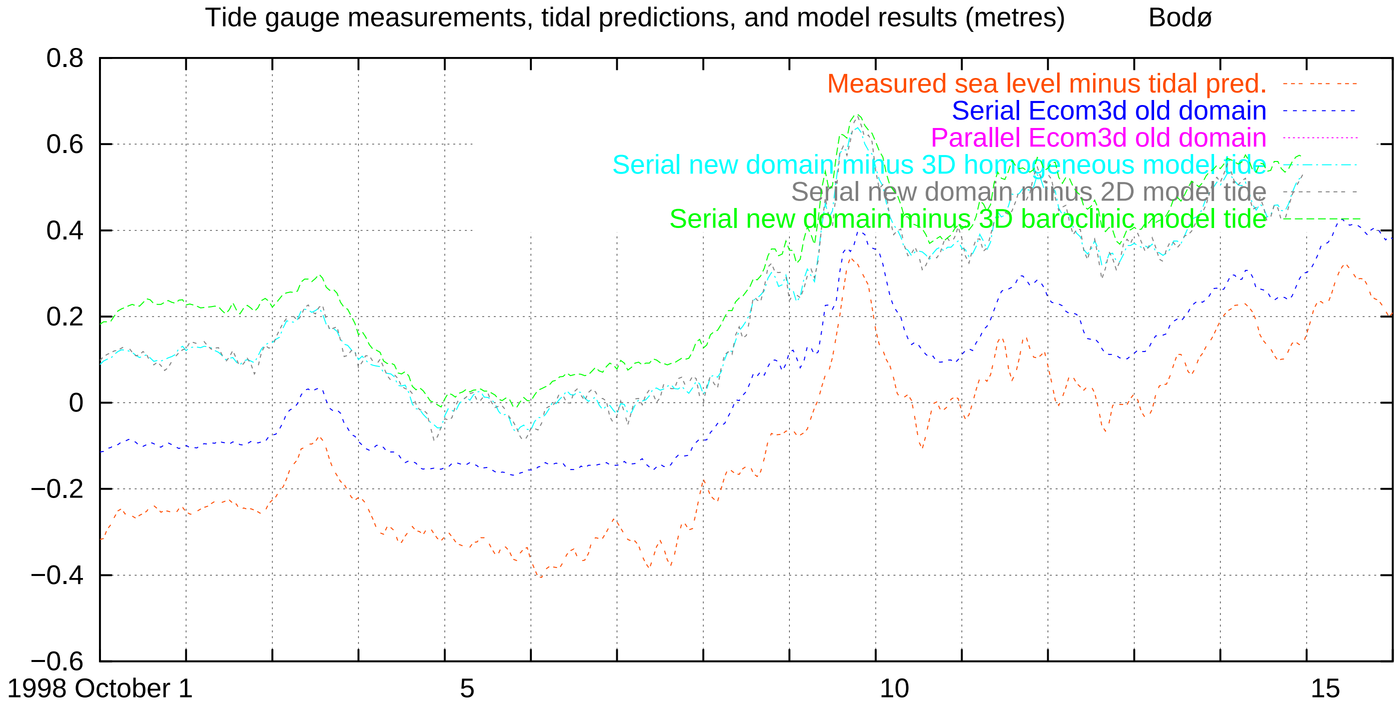

Fig. 63. Measured and modelled water level, excluding tides, Bodø, 1998 October 1–15

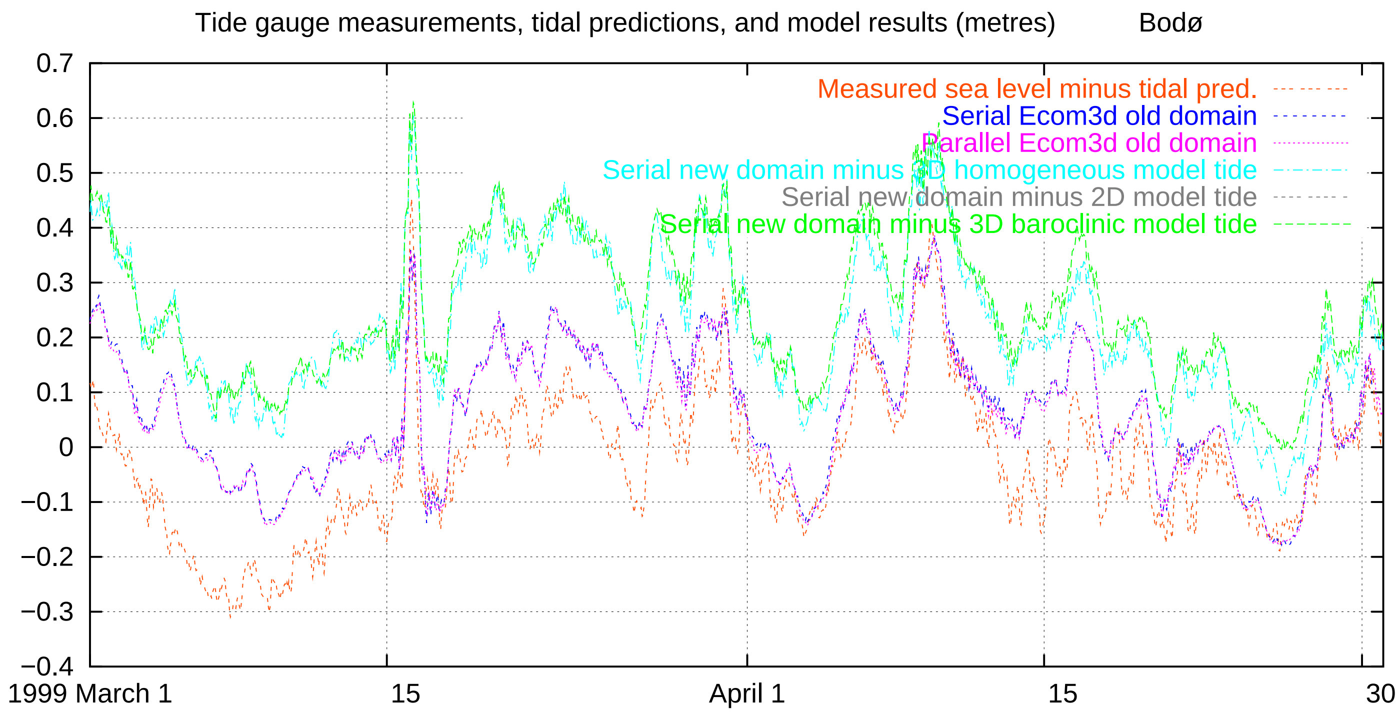

Fig. 64. Measured and modelled water level, excluding tides, Bodø, 1999 March–April

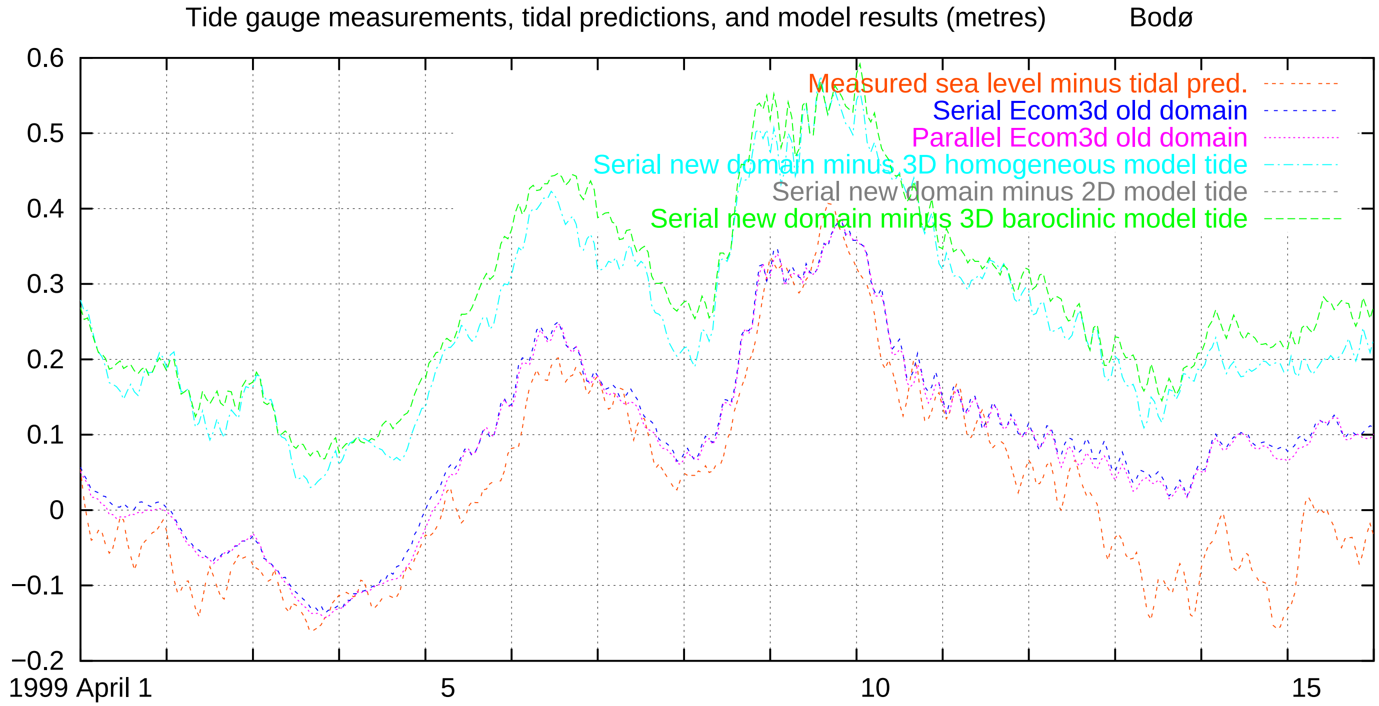

Fig. 65. Measured and modelled water level, excluding tides, Bodø, 1999 April 1–15

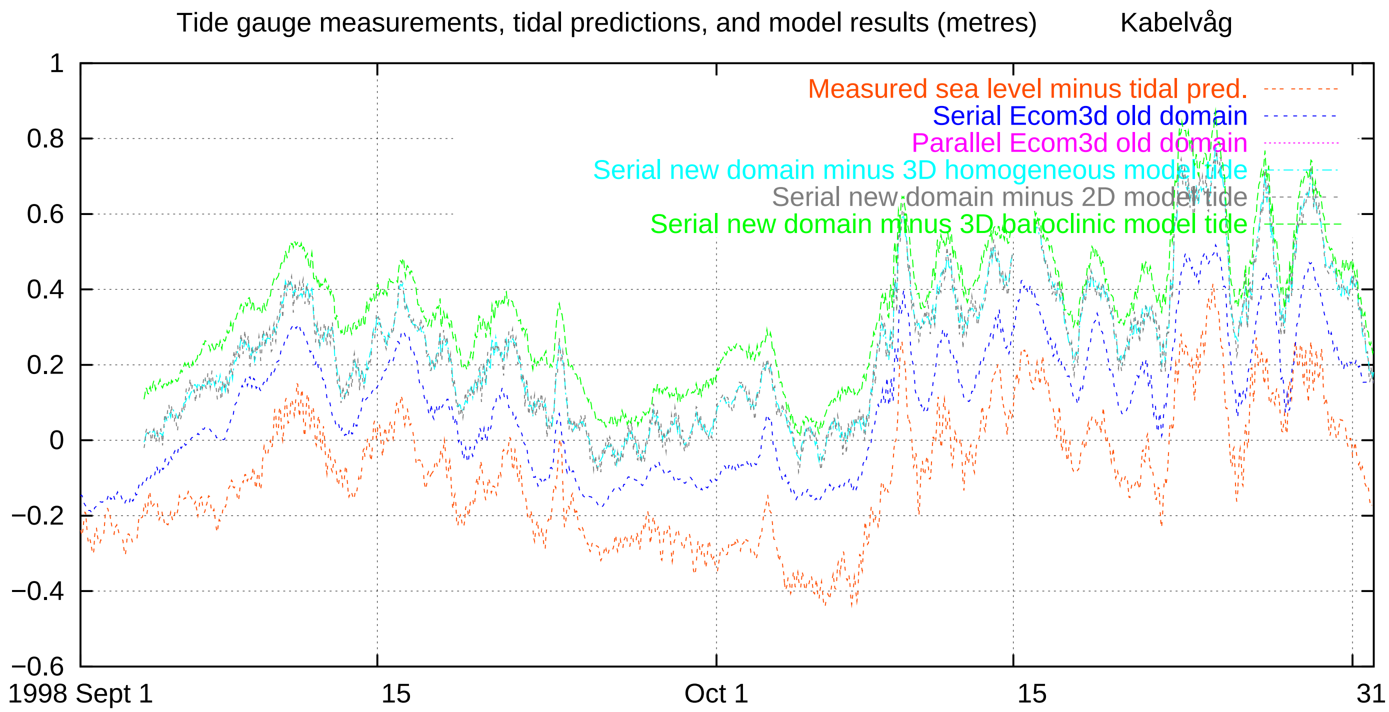

Fig. 66. Measured and modelled water level, excluding tides, Kabelvåg, 1998 September–October

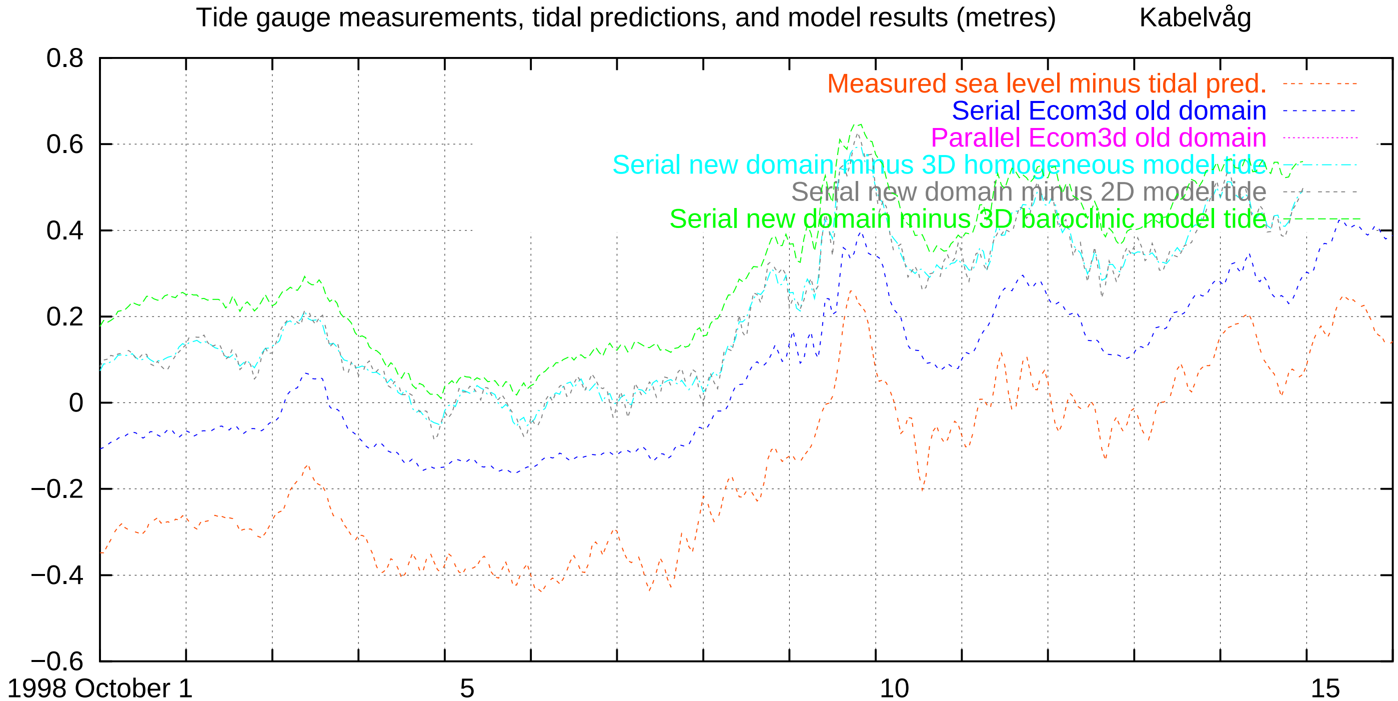

Fig. 67. Measured and modelled water level, excluding tides, Kabelvåg, 1998 October 1–15

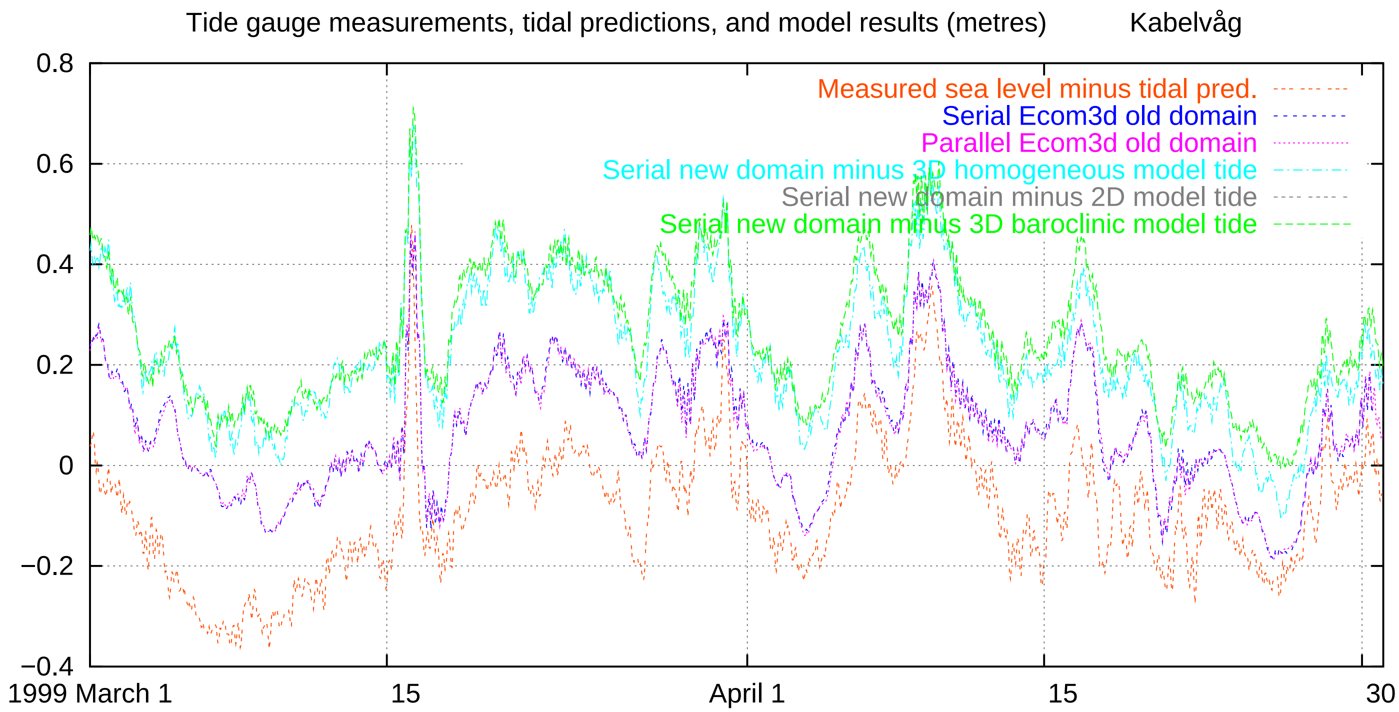

Fig. 68. Measured and modelled water level, excluding tides, Kabelvåg, 1999 March–April

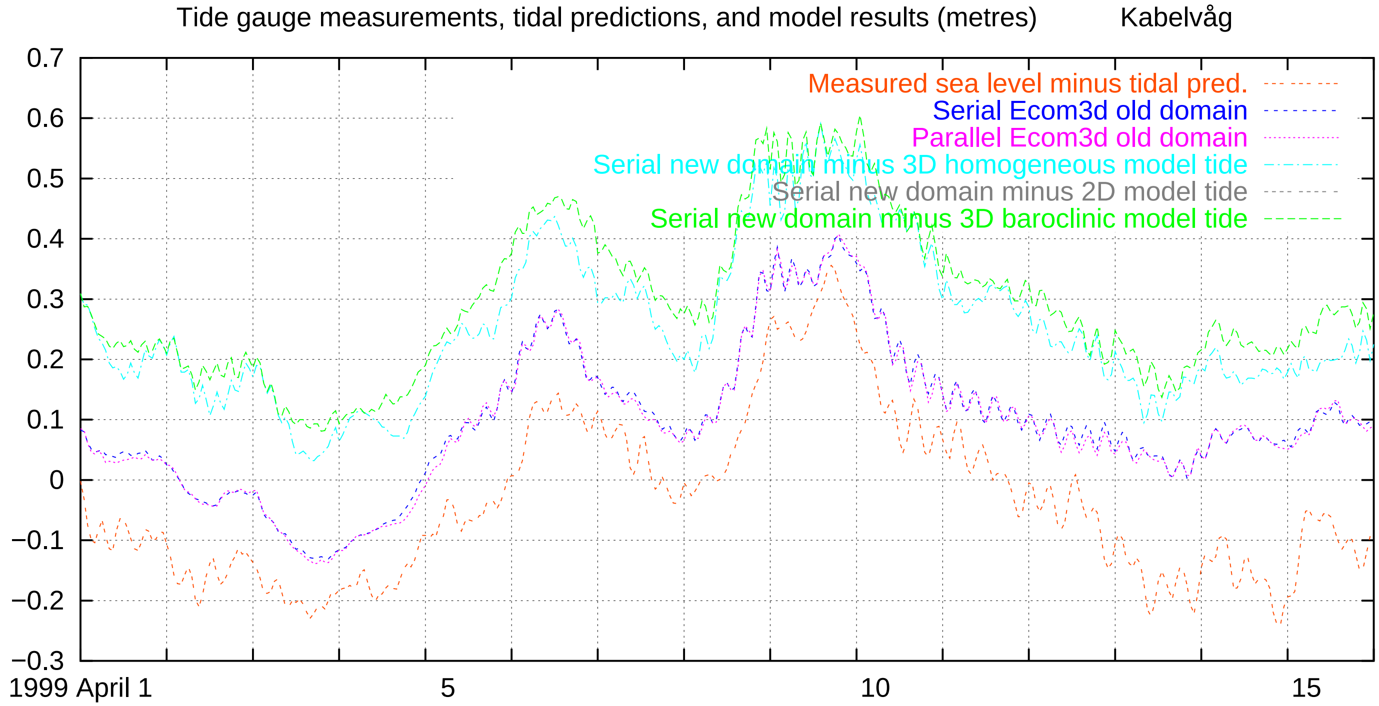

Fig. 69. Measured and modelled water level, excluding tides, Kabelvåg, 1999 April 1–15

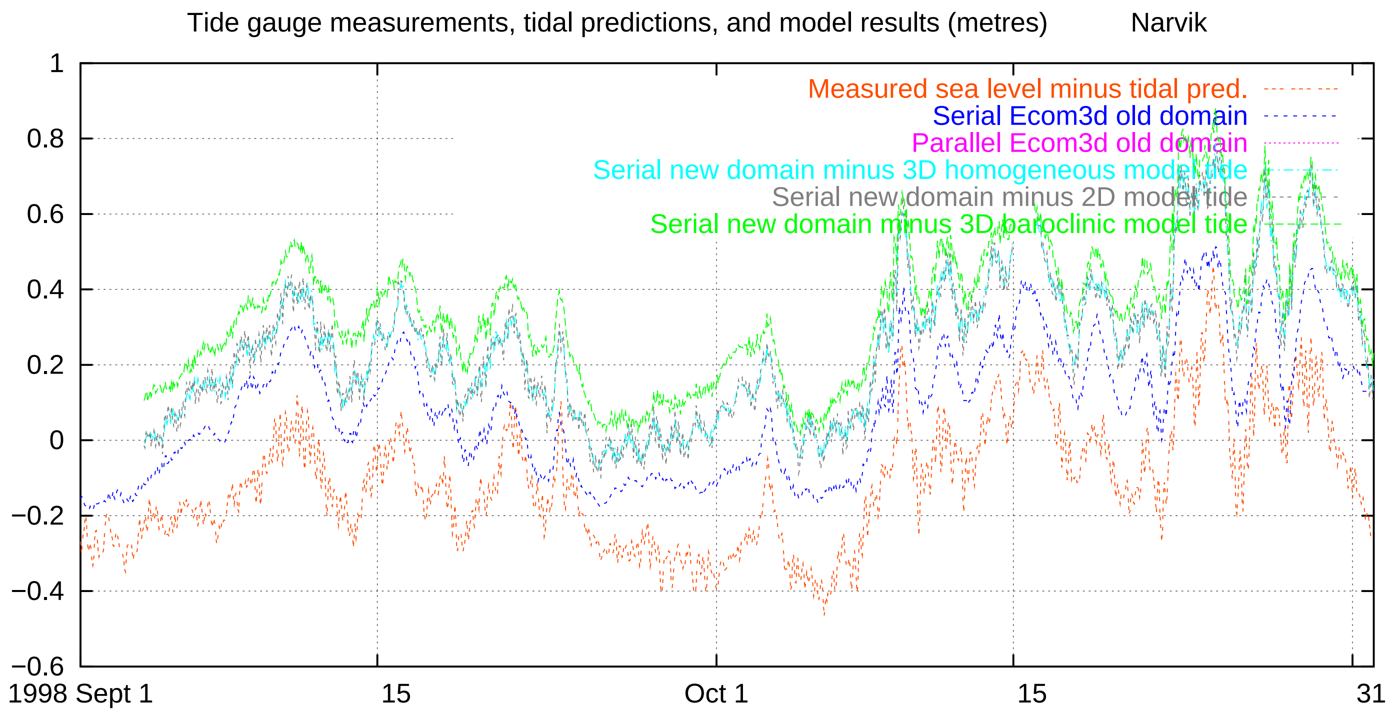

Fig. 70. Measured and modelled water level, excluding tides, Narvik, 1998 September–October

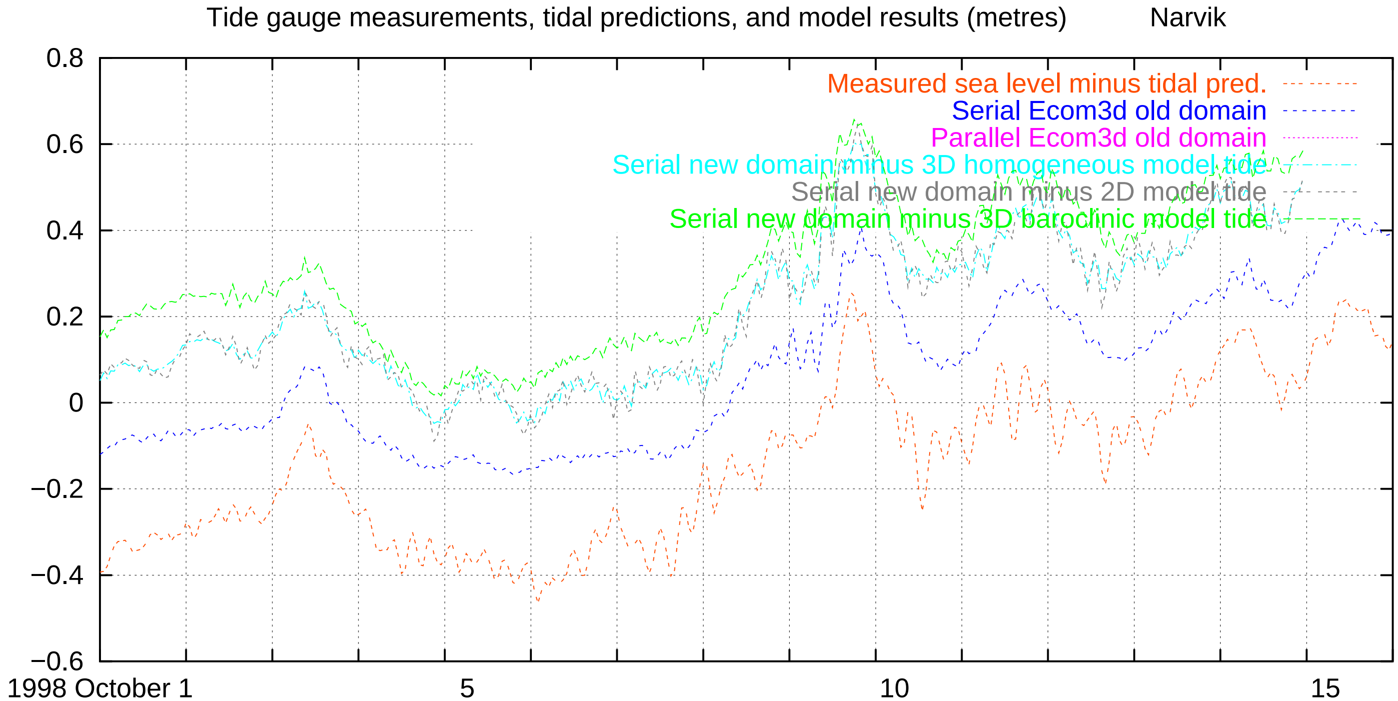

Fig. 71. Measured and modelled water level, excluding tides, Narvik, 1998 October 1–15

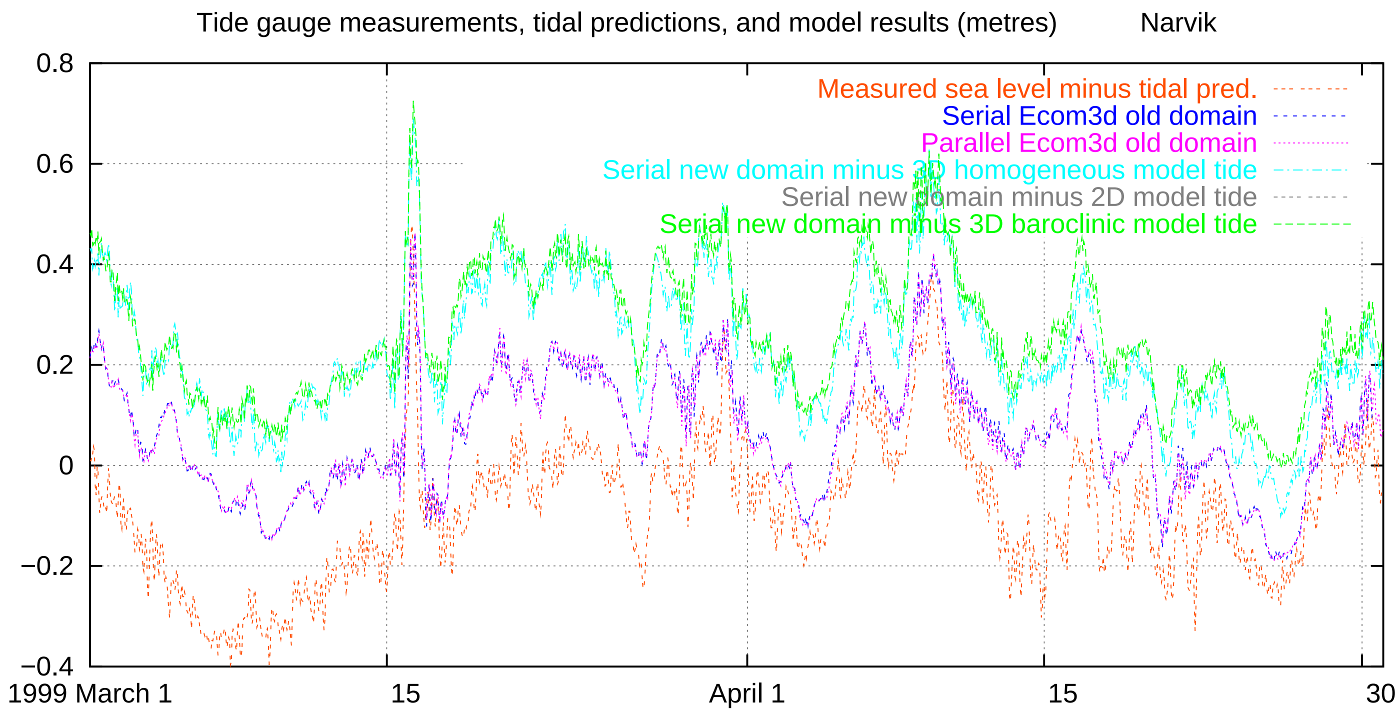

Fig. 72. Measured and modelled water level, excluding tides, Narvik, 1999 March–April

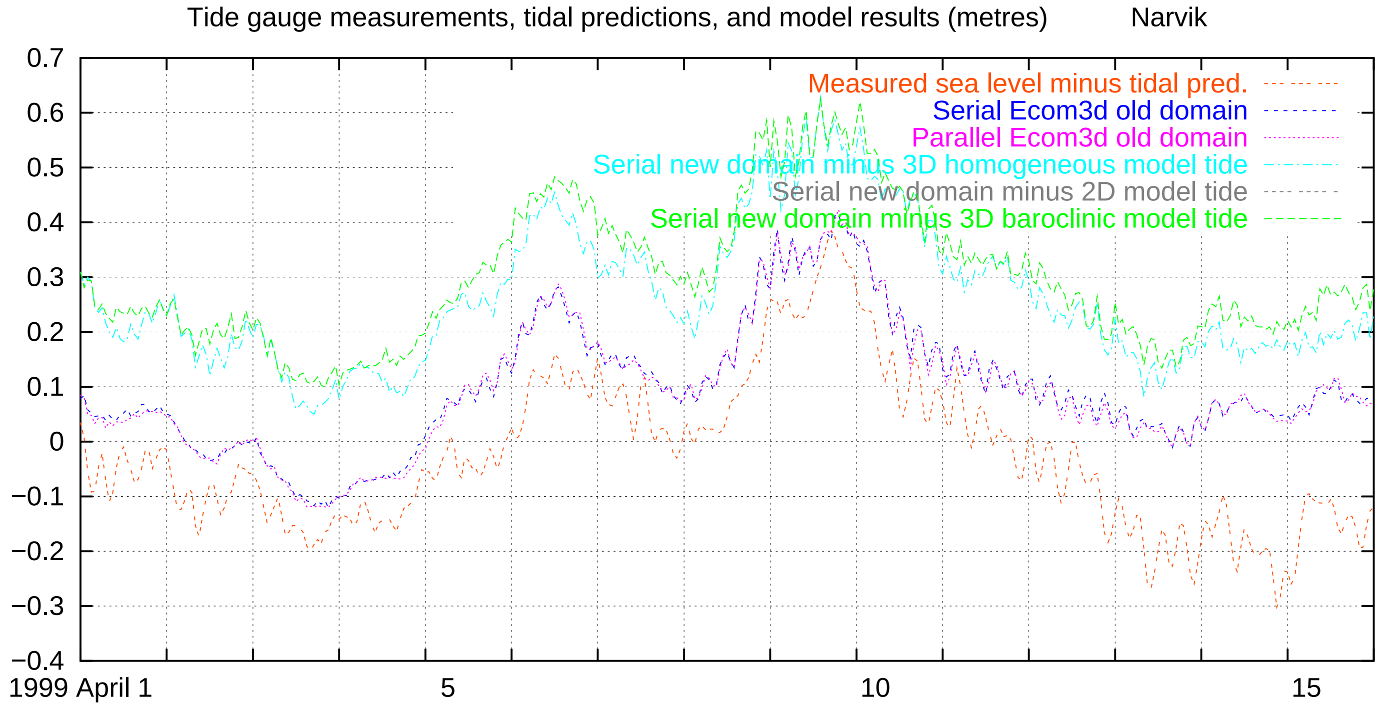

Fig. 73. Measured and modelled water level, excluding tides, Narvik, 1999 April 1–15

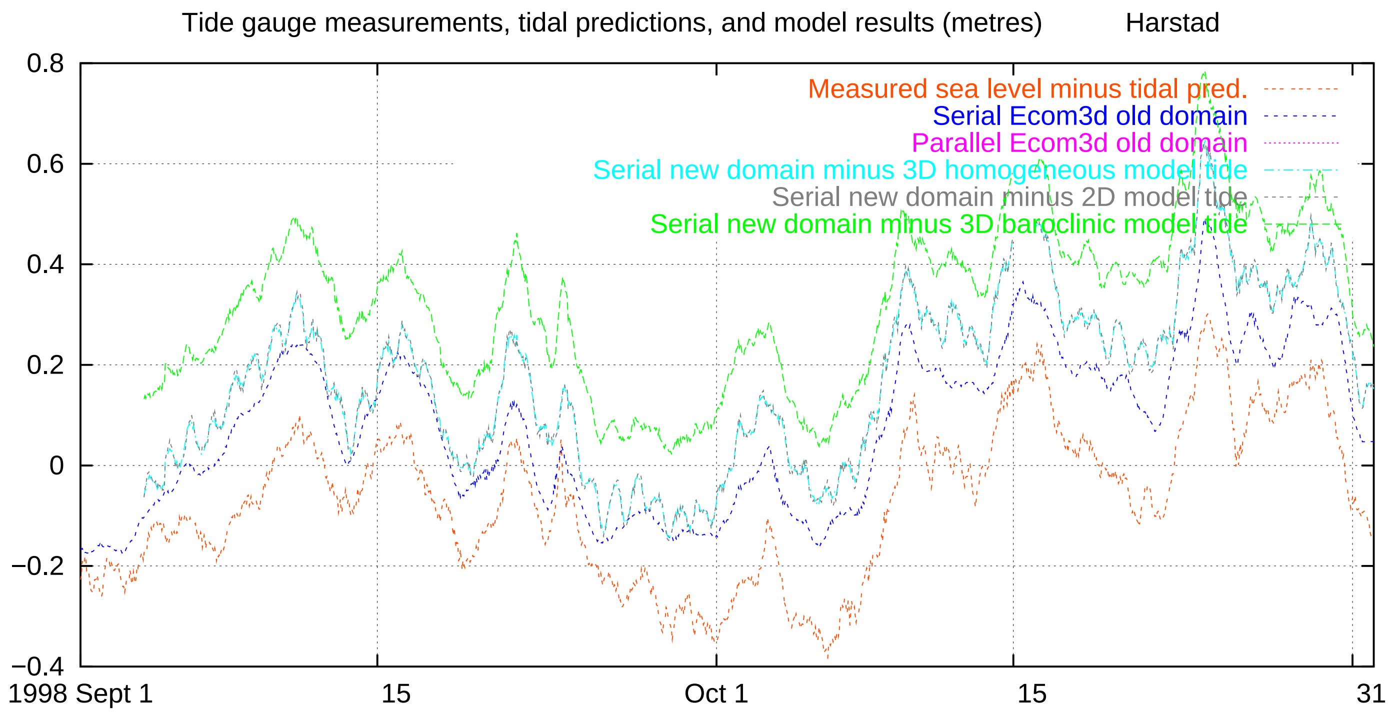

Fig. 74. Measured and modelled water level, excluding tides, Harstad, 1998 September–October

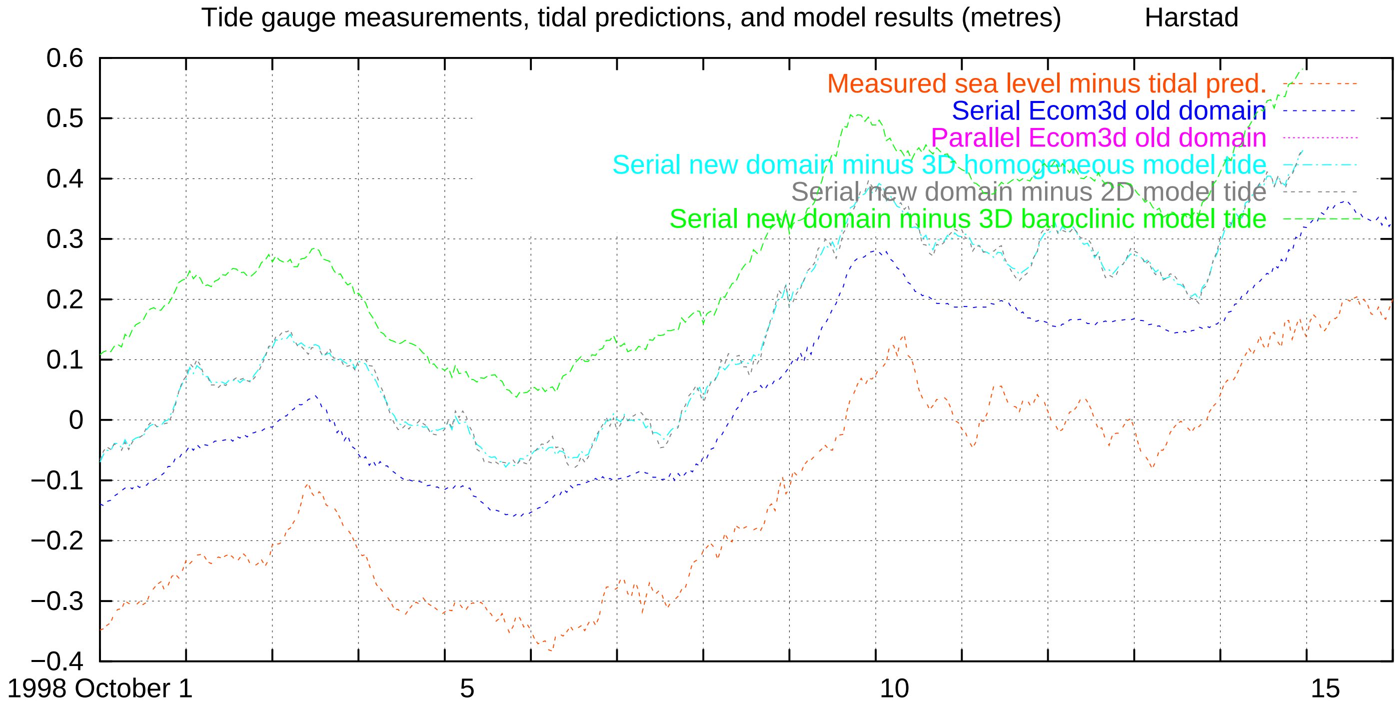

Fig. 75. Measured and modelled water level, excluding tides, Harstad, 1998 October 1–15

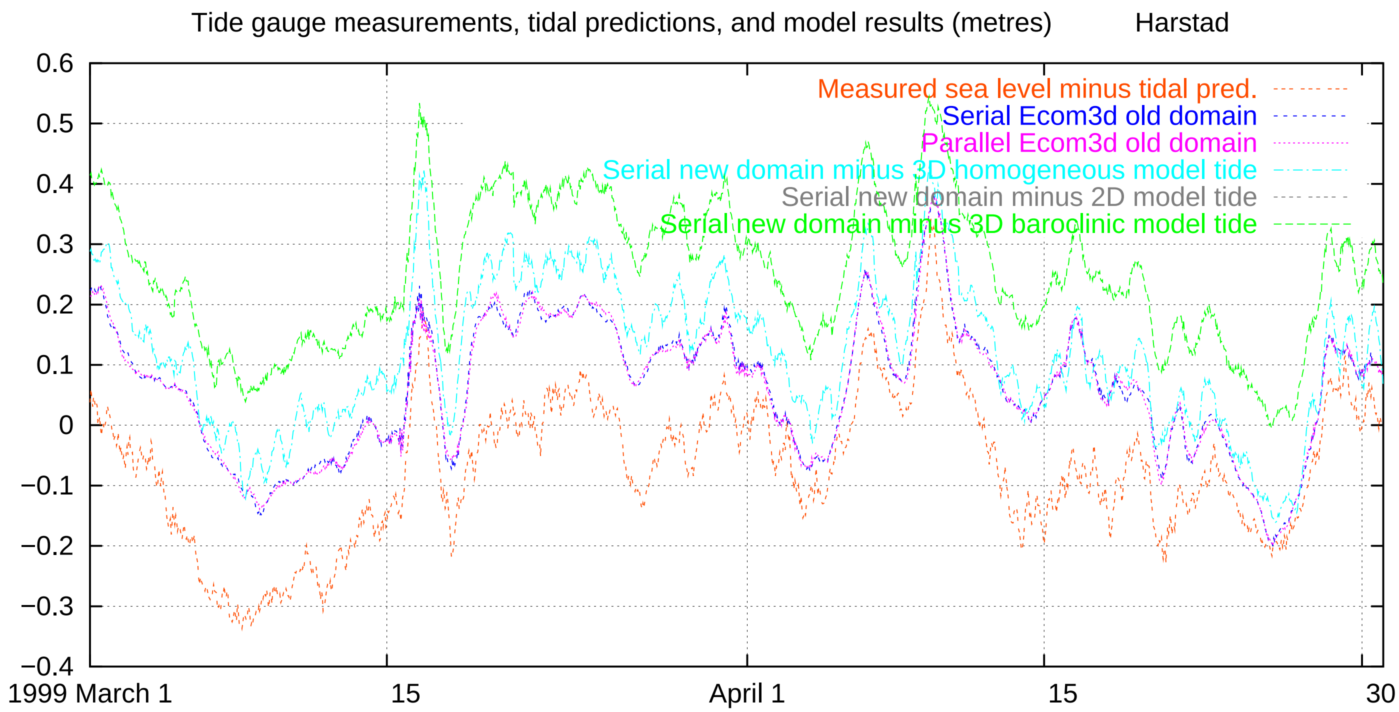

Fig. 76. Measured and modelled water level, excluding tides, Harstad, 1999 March–April

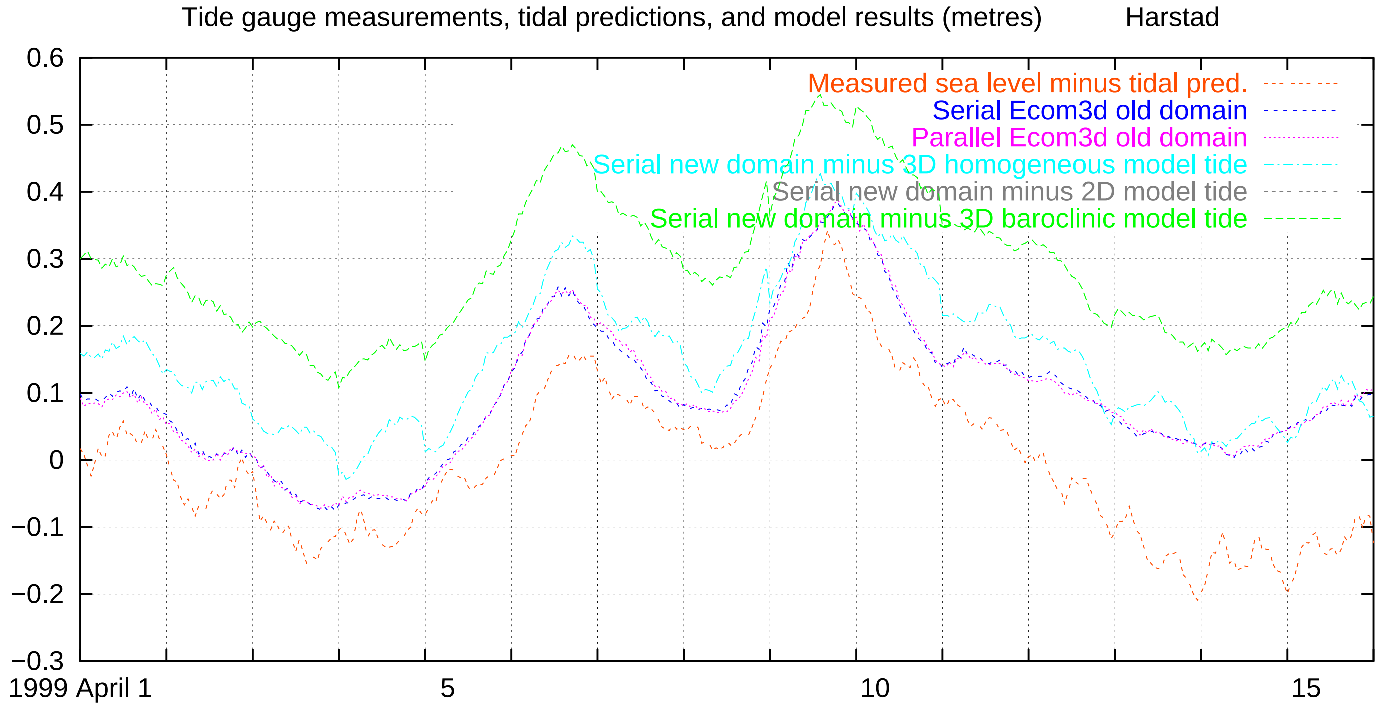

Fig. 77. Measured and modelled water level, excluding tides, Harstad, 1999 April 1–15

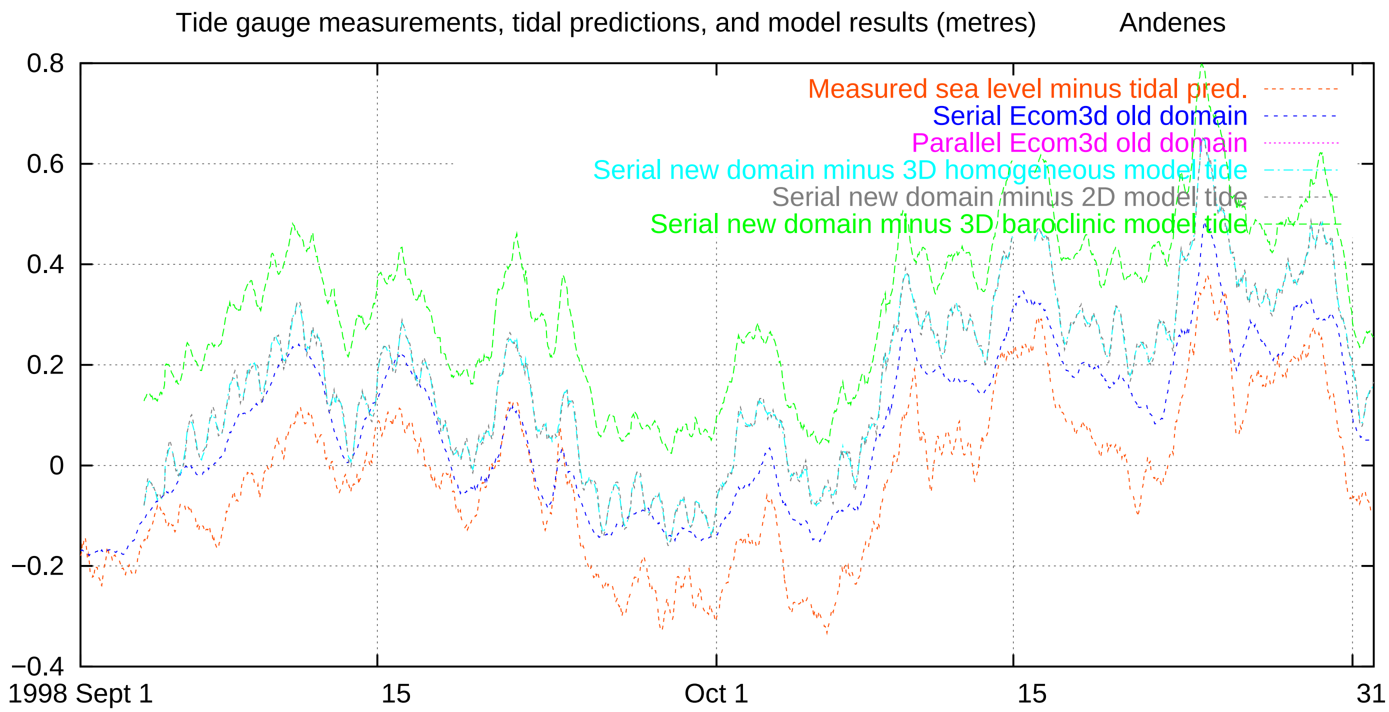

Fig. 78. Measured and modelled water level, excluding tides, Andenes, 1998 September–October

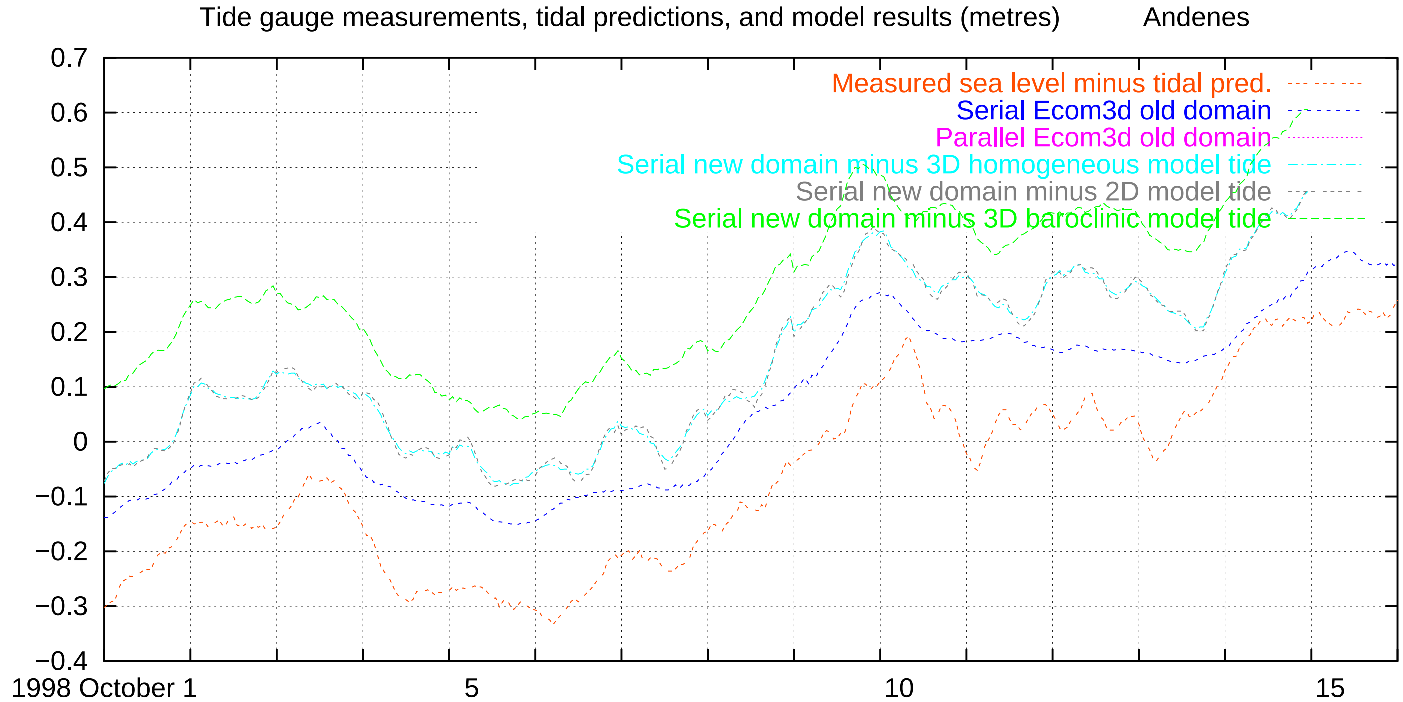

Fig. 79. Measured and modelled water level, excluding tides, Andenes, 1998 October 1–15

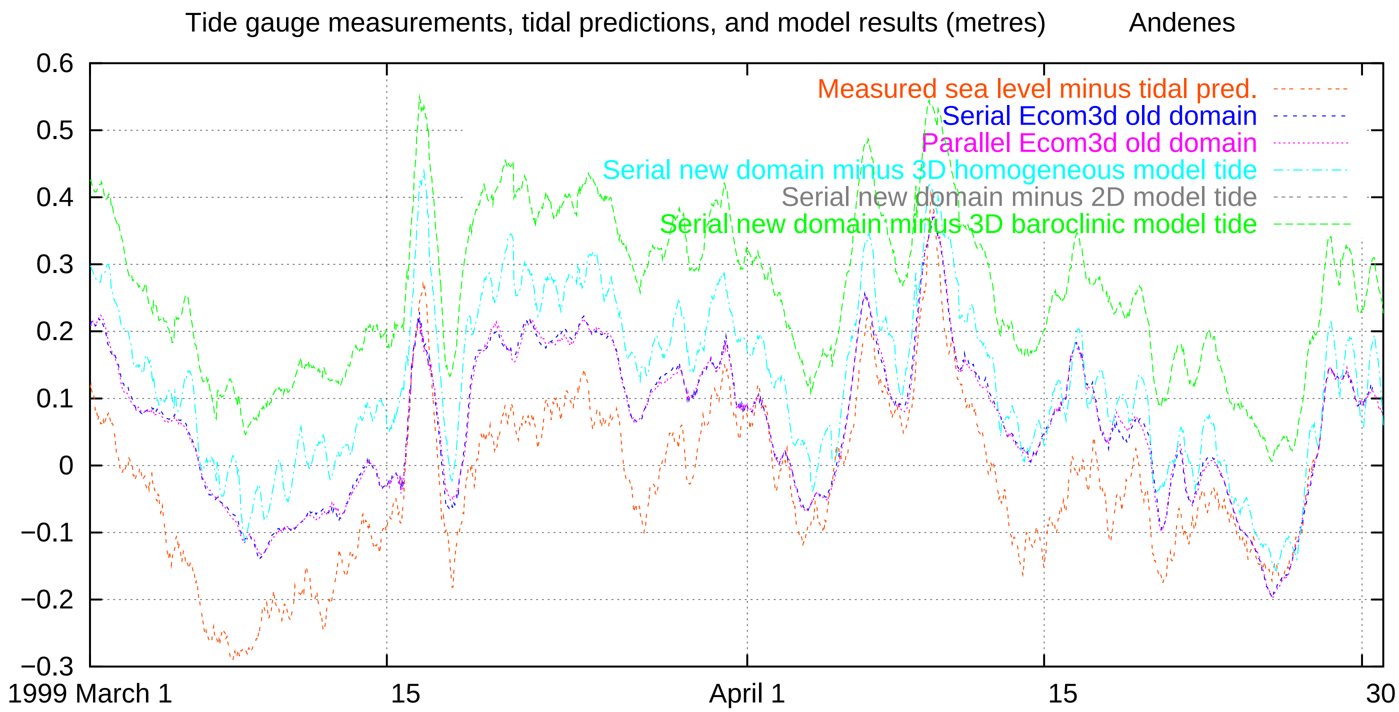

Fig. 80. Measured and modelled water level, excluding tides, Andenes, 1999 March–April

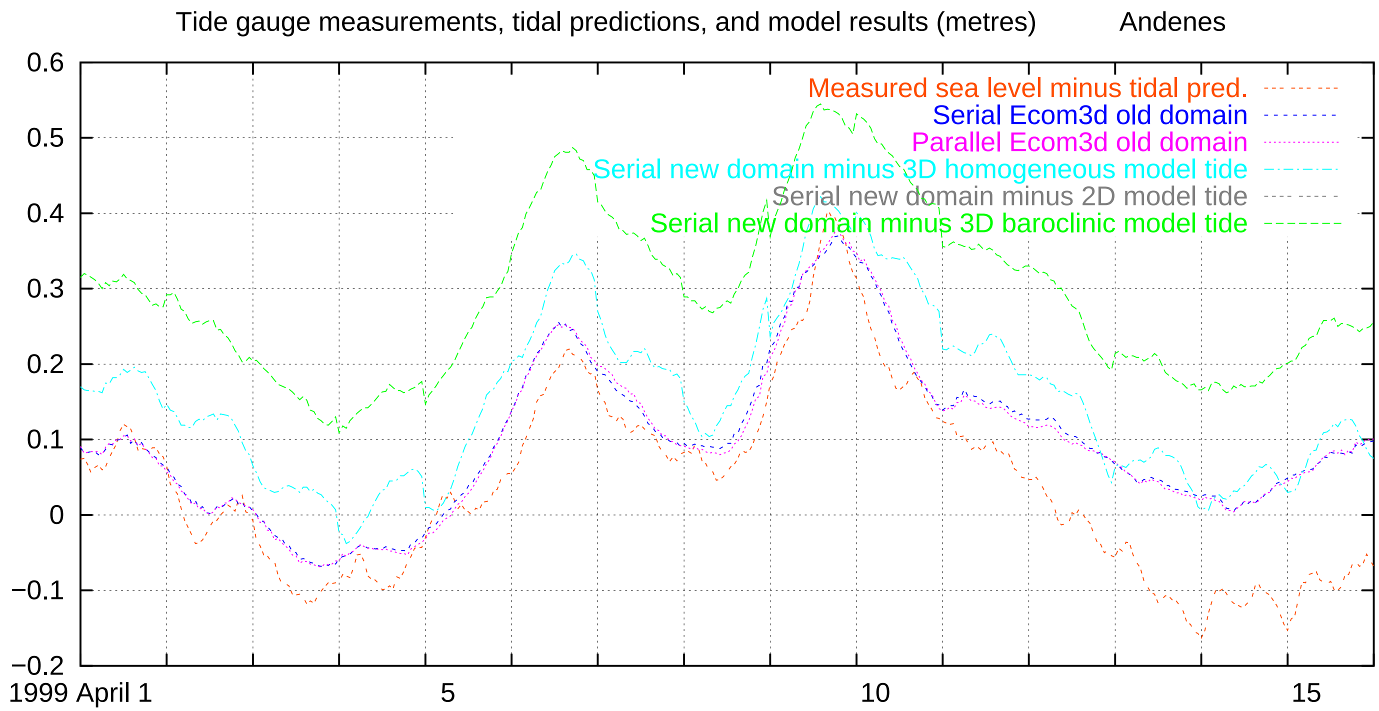

Fig. 81. Measured and modelled water level, excluding tides, Andenes, 1999 April 1–15

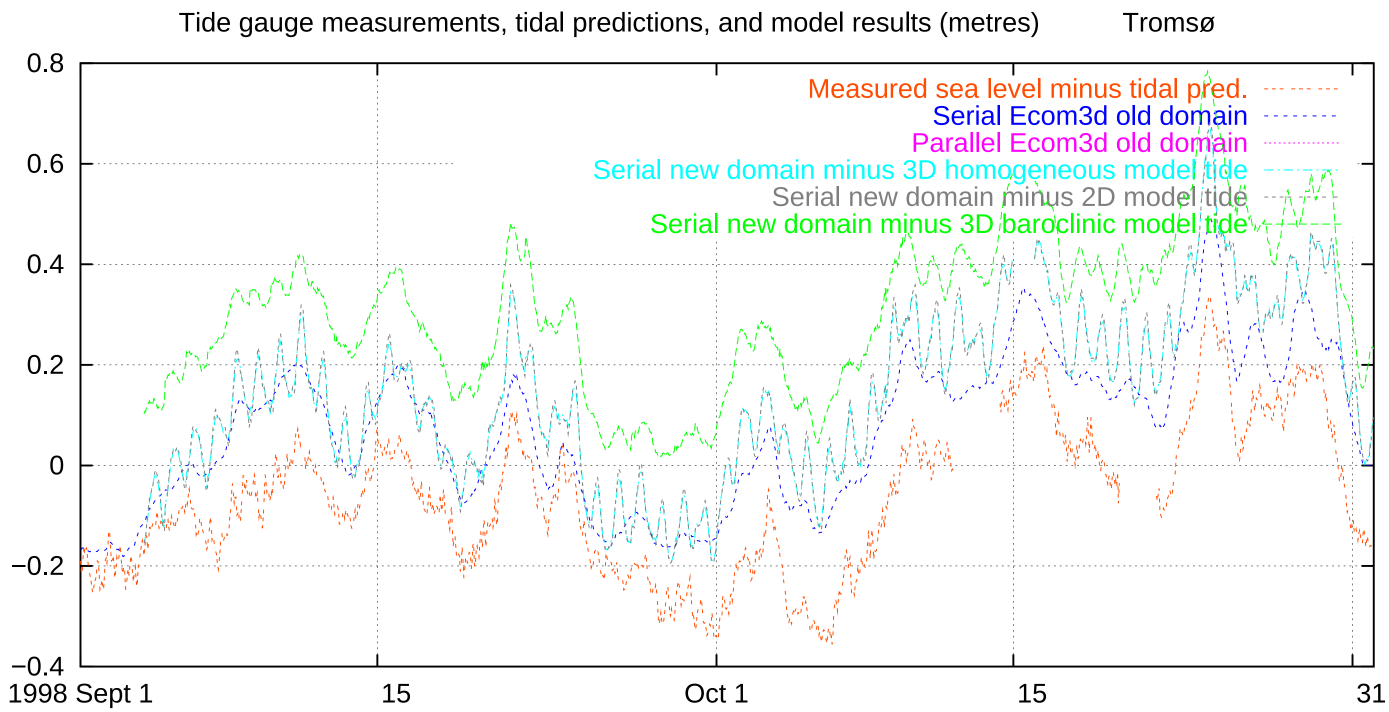

Fig. 82. Measured and modelled water level, excluding tides, Tromsø, 1998 September–October

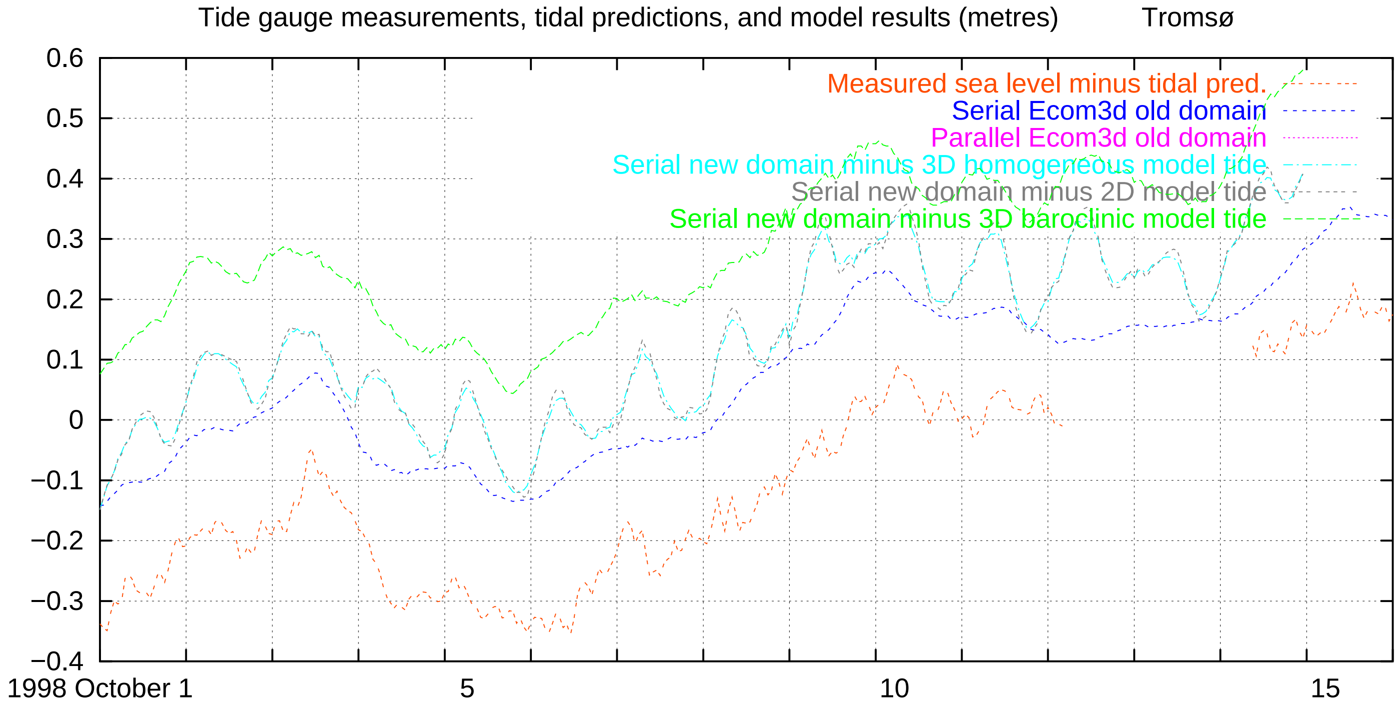

Fig. 83. Measured and modelled water level, excluding tides, Tromsø, 1998 October 1–15

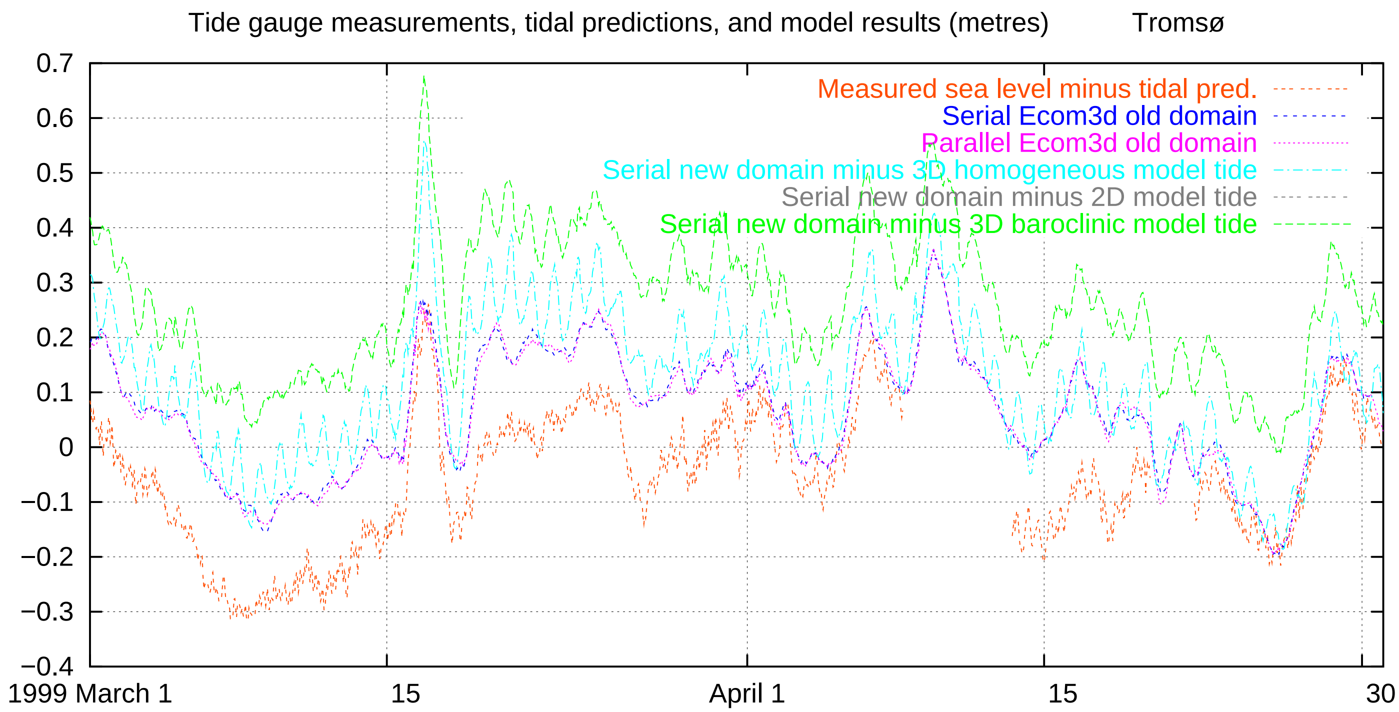

Fig. 84. Measured and modelled water level, excluding tides, Tromsø, 1999 March–April

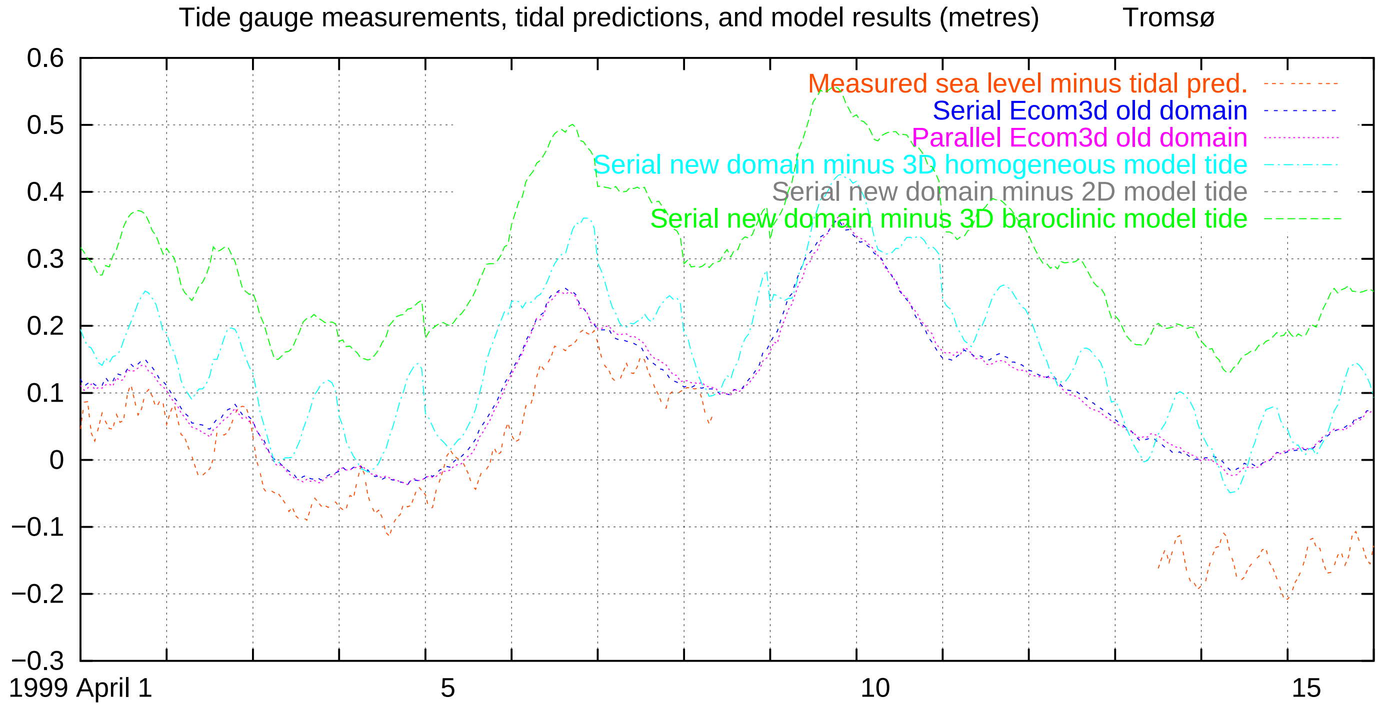

Fig. 85. Measured and modelled water level, excluding tides, Tromsø, 1999 April 1–15

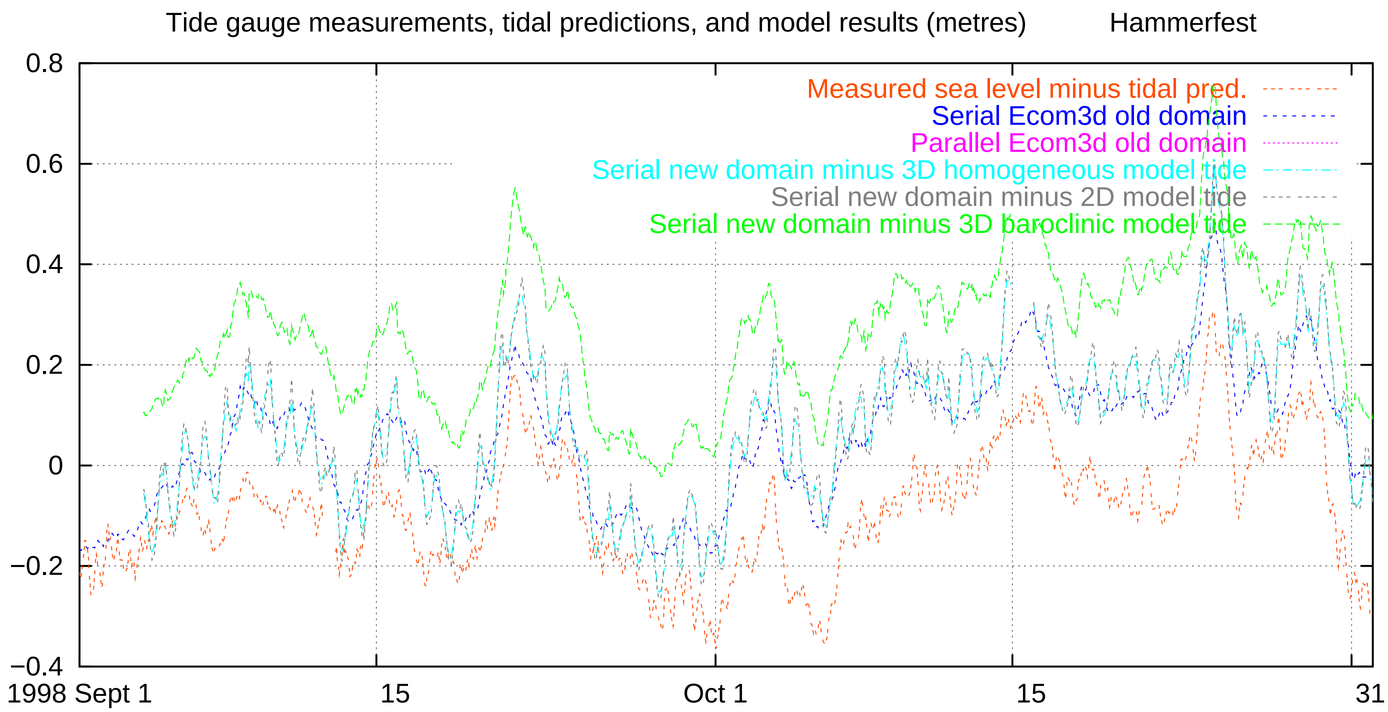

Fig. 86. Measured and modelled water level, excluding tides, Hammerfest, 1998 September–October

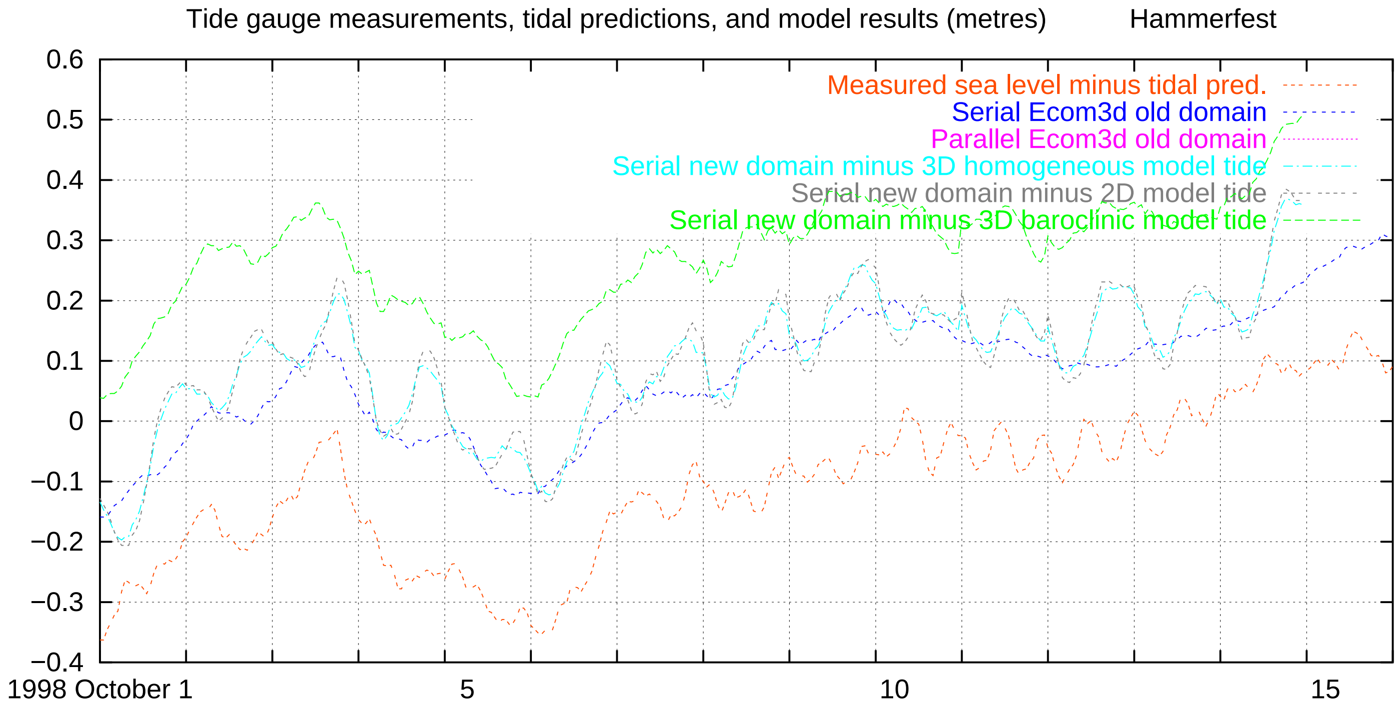

Fig. 87. Measured and modelled water level, excluding tides, Hammerfest, 1998 October 1–15

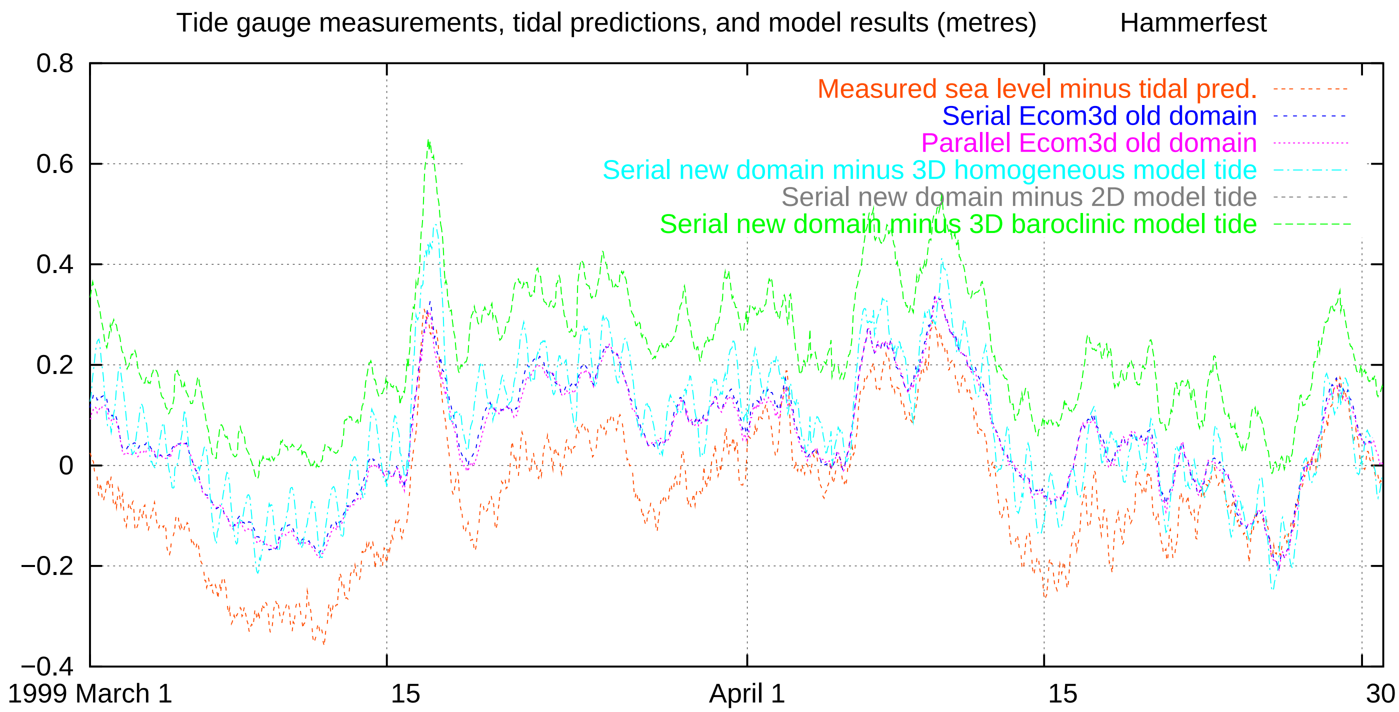

Fig. 88. Measured and modelled water level, excluding tides, Hammerfest, 1999 March–April

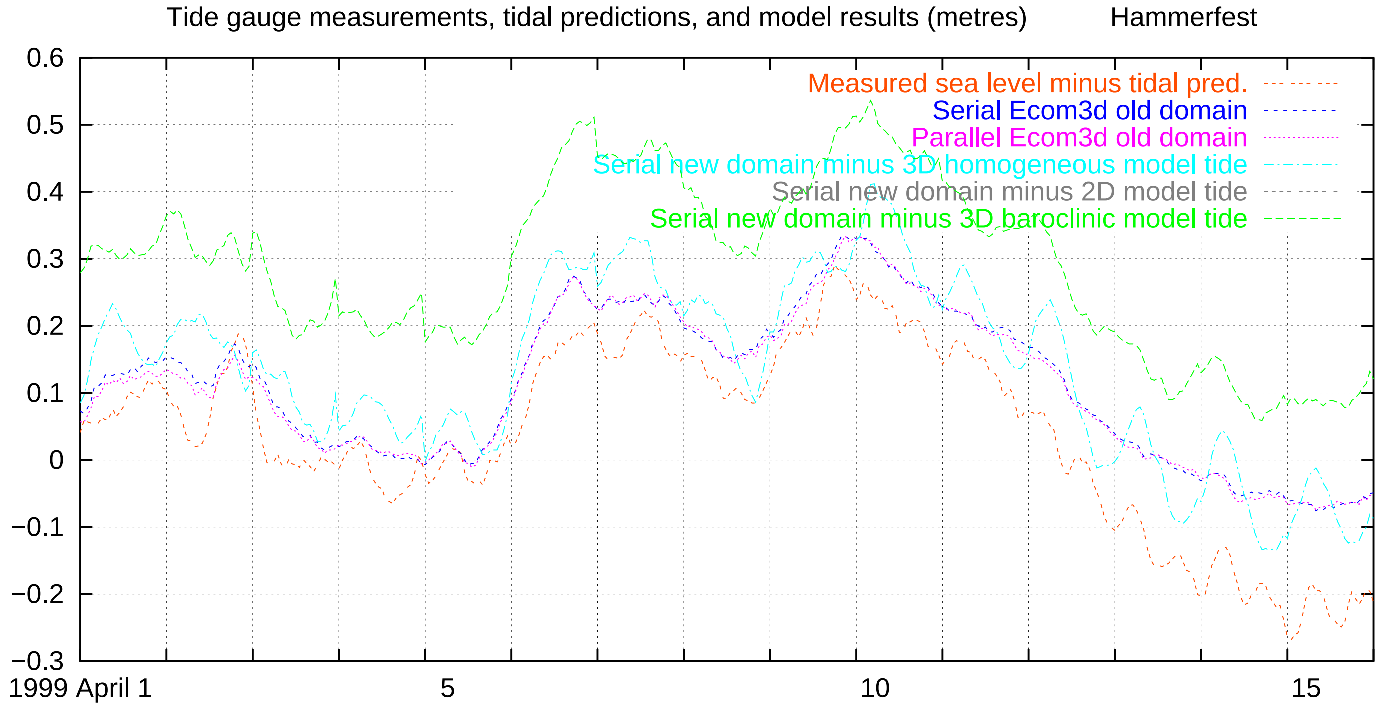

Fig. 89. Measured and modelled water level, excluding tides, Hammerfest, 1999 April 1–15

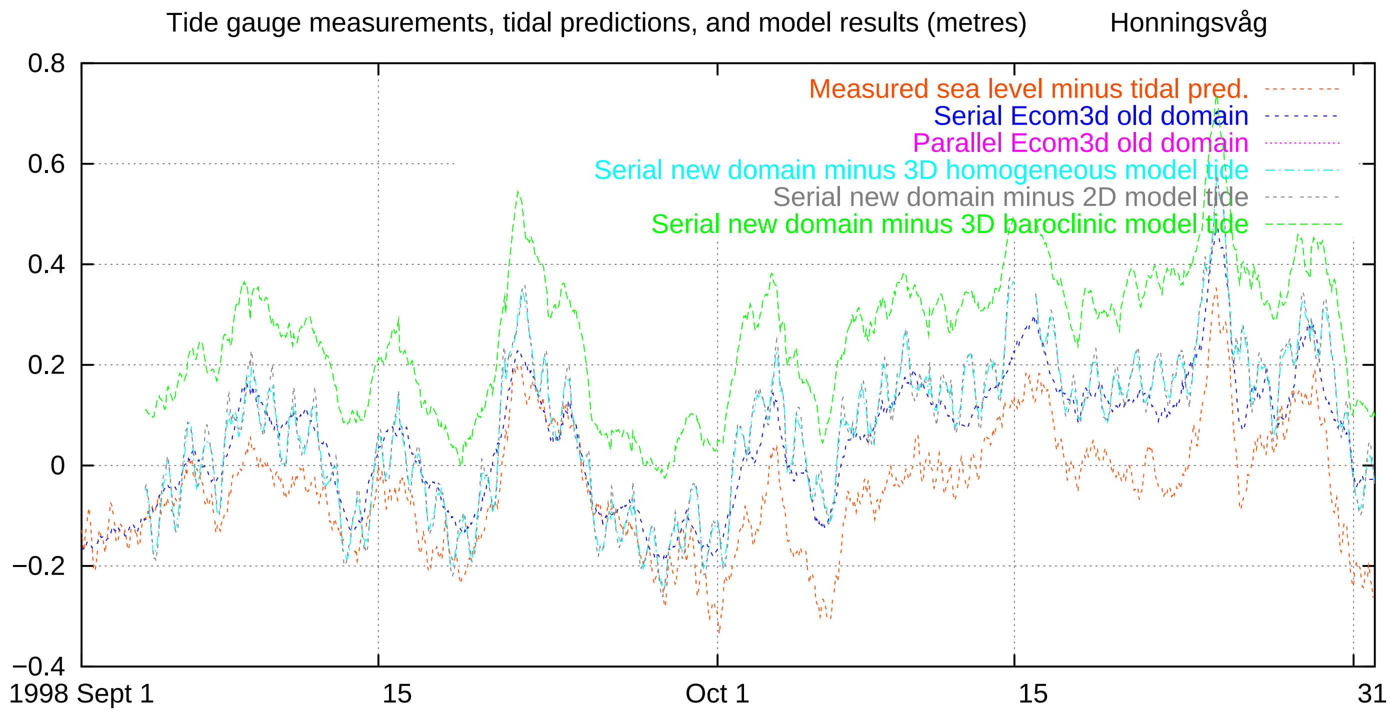

Fig. 90. Measured and modelled water level, excluding tides, Honningsvåg, 1998 September–October

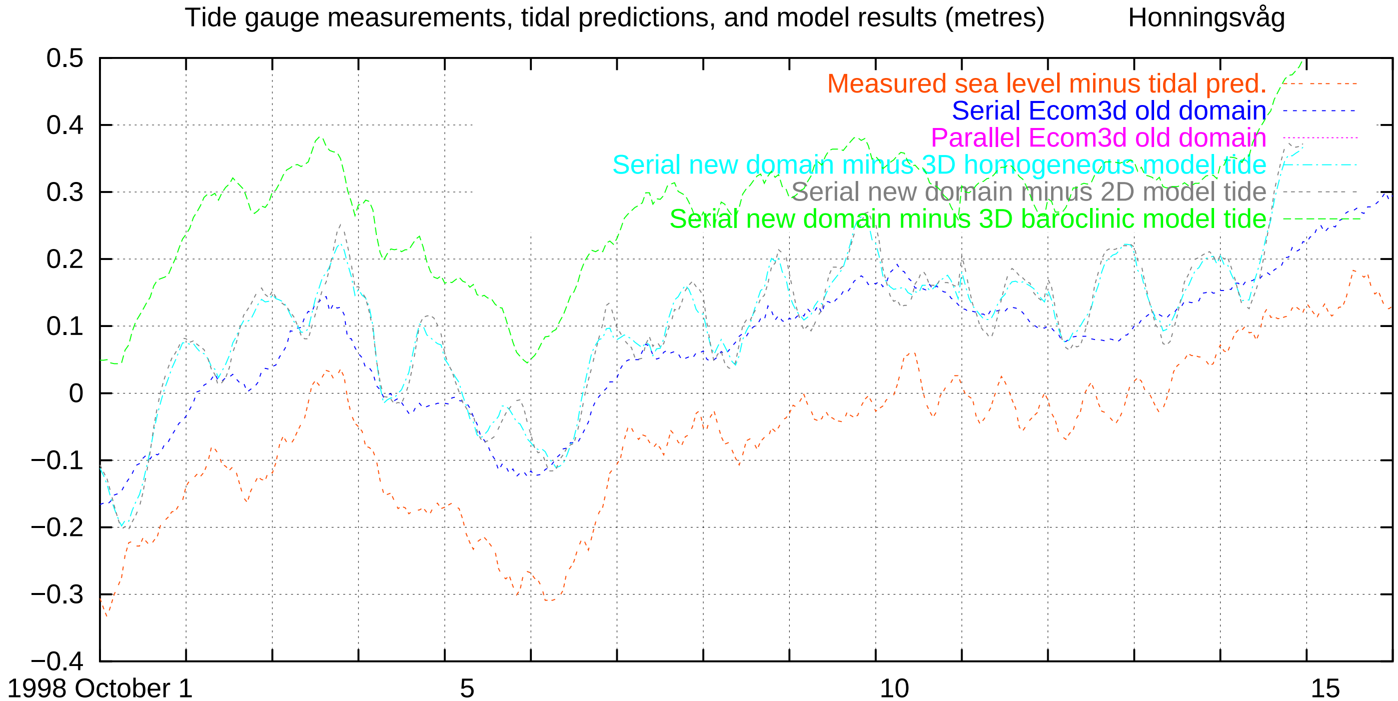

Fig. 91. Measured and modelled water level, excluding tides, Honningsvåg, 1998 October 1–15

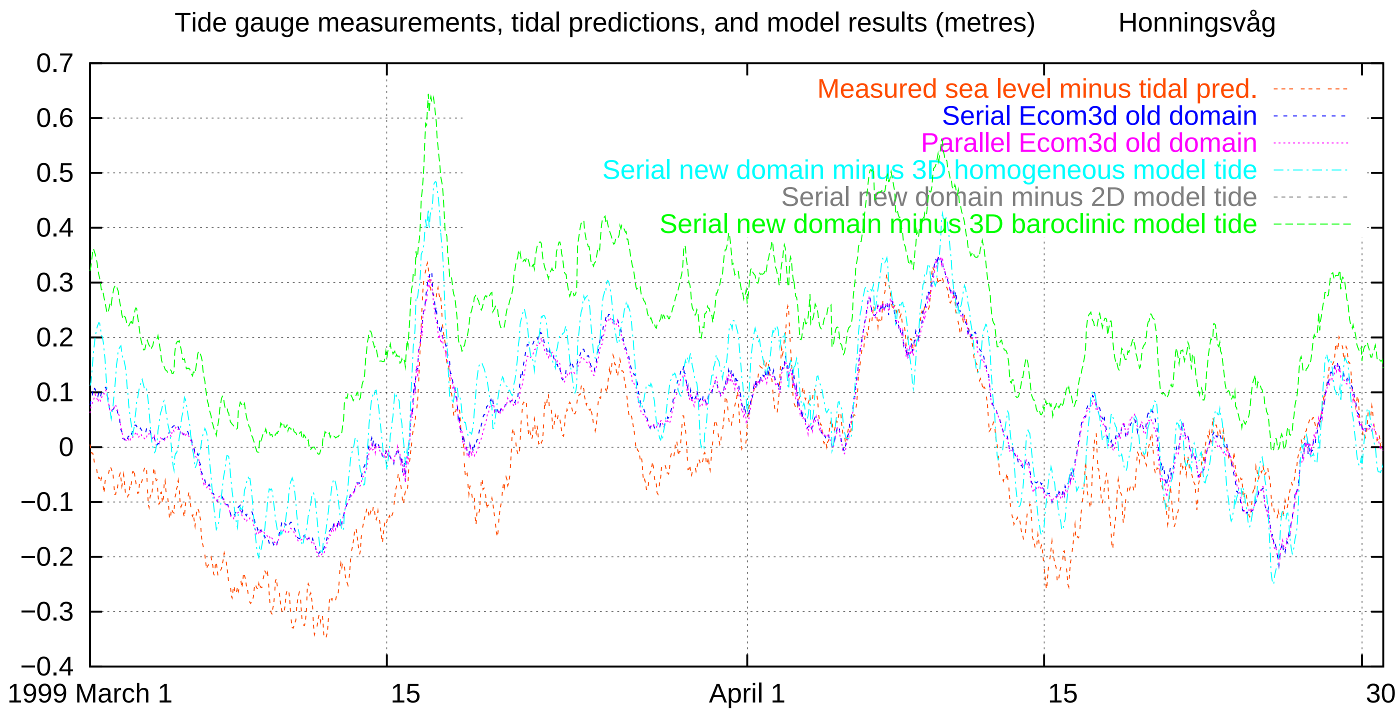

Fig. 92. Measured and modelled water level, excluding tides, Honningsvåg, 1999 March–April

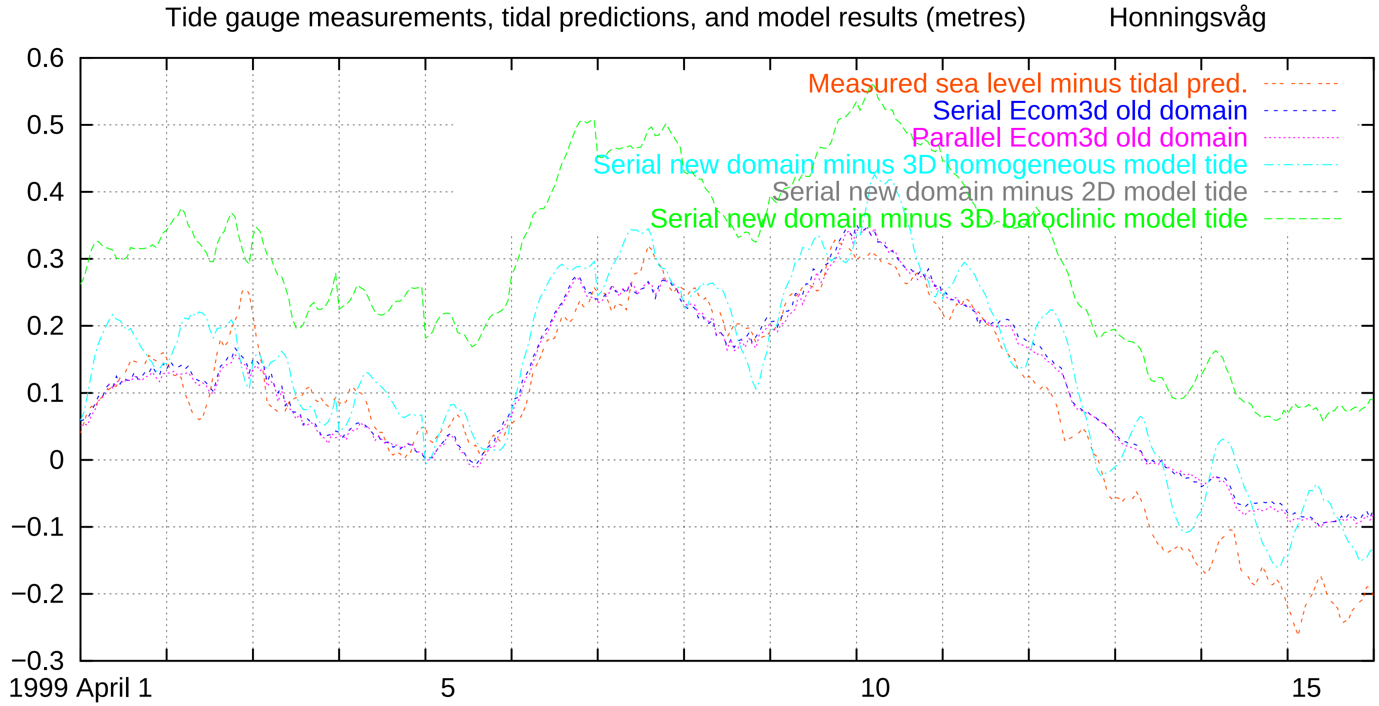

Fig. 93. Measured and modelled water level, excluding tides, Honningsvåg, 1999 April 1–15